NATURAL & ARTIFICIAL SEWAGE TREATMENT

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AND
H. ALFRED ROECHLING M. INST. C.E.

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BY

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PREFACE.

THE Authors, some time ago, read before different Societies of professional men, Papers * dealing with the Natural and Artificial Purification of Sewage, and as these were favourably received, the thought occurred to them that the time might be opportune for making the information there given available for a wider public.

As, however, a mere republication of the Papers would have been against the rules of the Societies concerned, the Authors decided to re-write entirely the subject matter, and to bring it up to date, so that the present publication is not a mere repetition of their old Papers clothed in a new garb, but an entirely fresh publication, right up to date.

The Authors hope that they have given the information in such a form as to be readily available for District Councillors, Sanitarians, and all interested in this complicated subject.

When considering natural and artificial sewage treatment, it ought to be borne in mind that in the natural treatment we

* 'Sewage Treatment: Science with Practice.' By Colonel A. S. Jones, V.C., C.E. Read at the International Engineering Congress at Glasgow, 1901. And 'The Sewage Question during the Last Century.' Read by H. Alfred Roechling, M. Inst. C.E., F.G.S., F.S.I., etc., on December 2, 1901, before the Society of Engineers, and awarded the Gold Medal of the Society.

have to deal with one treatment only, and that, in order to bring the results obtained from artificial processes up to the same standard, the artificial treatment ought to be supplemented by a treatment for the removal of nitrates from the effluent, and another for the removal of pathogenic micro-organisms, which means one treatment in natural, as against three separate treatments in artificial purification.

In addition to this it must be understood that, owing to the great losses by evaporation and by growing plants, which are continually at work on sewage farms, especially during the summer months, when, as a rule, the flow of water in the brook that takes the effluent is smallest, the quantity of the effluent from the natural treatment is probably only from one-half to one-third that resulting from the artificial treatment, which is a point of very great importance.

If it can be proved to them that Nature is not sure and true enough in its methods, the Authors are prepared to assist it with methods and means produced by the inventive brain of man. But if such proof is not forthcoming, they adhere—in preference to groping in the dark—to Nature's own methods, knowing from experience, that when allowed full scope and fair treatment, it is most sure in all its ways. That will not prevent them, however, from giving in the future, as they have done in the past, the question of sewage treatment in all its aspects their most careful consideration.

ALFRED S. JONES.
H. ALFRED ROECHLING.

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SEWAGE TREATMENT.

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"HOW extremely simple it all is!" was the remark of a recent visitor at a sewage farm—which encourages me to venture on publication of the most recent discussions on a "problem" complicated by engineers, chemists, bacteriologists and inventors of systems, who have raised clouds of dust through which it is difficult for ratepayers and district councillors to find their way to "the best practical and available means of sewage disposal." **Introductory remarks.**

I have a belief that publication of all attempts to purify *the whole* of a town's sewage, rather than small scale experiments with equations founded on such data, is the desideratum.

Having begun in the year 1872, with a pamphlet, "Will a Sewage Farm Pay?"* I desire to proceed with the present one thirty years later, as my humble contribution to a right understanding of the intelligent Scavenger's business. **1872.**

At the earlier date agriculture was prosperous, and ratepayers of Exeter were just as confident that sewage farming would bring large dividends as some of the same

* Published by Longmans, London, 1874. Third edition published by R. Potter, Wrexham, 1885.

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city's councillors are at present not in the least sceptical that their engineer's septic system is the true specific for sewage disposal.

In adhering to land as the natural and best agent, I have had the support of the Local Government Board with that of many Royal Commissions, notably the one now sitting, and I have naturally chosen cases where suitable land was accessible when I desired to demonstrate the efficiency and simplicity with which the powers of Nature can be applied for the use and convenience of man.

Nor have I failed to study all "artificial" substitutes for the best means, wherever difficulties of obtaining suitable land presented themselves, e.g. my Canvey Island scheme for dealing with the sewage of London on a relatively small area, and other cases.

Of late years I have welcomed the light thrown on this subject by bacteriologists, but lamented extravagant statements put forward by those who fail to see that the previously unrecognised microbes can do their work, as they have always done it, to most advantage in the upper layers of any porous land.

1902. An interim report by Lord Iddesleigh's Royal Commission has, however, awakened such theorists to the fact that land is not to be discarded because it may not bring in a profit or because patentees of systems find it to their interest to contrast neglected or badly managed sewage farms with carefully nursed little experimental installations for artificial treatment of selected samples of sewage.

Recognising the marvellous improvements in arts and manufactures of all kinds due to steam, chemistry and electricity, the public has naturally expected similar results from applied science in artificial sewage treatment,

and there has been no lack of study of every imaginable process during the last thirty years.

But the late Lord Bramwell's Royal Commission on Metropolitan Sewage Discharge established two very important points of general application, namely:—

1884. Lord Bramwell's Royal Commission establishes principles.

1. The principle of separation in works of sewerage and drainage; and

2. The fact that the suspended matters in town sewage can be very effectually removed from its liquid by *simple deposition* without the aid of any chemical reagent.

And Mr. Dibdin three years later began to demonstrate the mistaken policy of adding lime or any other precipitating agent in any quantity likely to arrest the natural agency of abundant bacterial life, which ultimately disposes of all dead and effete organic matter by forming gases or natural compounds, with more or less offence to human senses, according to the supply of oxygen and rate at which these bacteria can carry out their work.

1887. The chemist Dibdin discards chemical reagents in favour of M. Pasteur's aerobic organisms.

It was soon found that the bacteria of two classes, aerobe and anaerobe, abound in sewage, and the latest Leeds experiment with the continuous or trickling filter show the marvellous rapidity with which the *aerobic* microbes at any rate, can accomplish their task where air and liquid sewage are sufficiently diffused in the pores of a filter; while Mr. Cameron, C.E., at Exeter has shown rapid evolution of gases and considerable solution of organic solids by *anaerobic* microbes in a septic tank.

Leeds and Exeter.

But the enthusiasm of inventors and their converts has made too much of the benefit to the human race supposed to be conferred by the bacterial discovery of M. Pasteur as applied by them to sewage treatment.

Without detracting from the credit due to the great

French savant and other bacteriologists who have followed up his interesting studies of ferments for the last fifteen years, the practical man may well ask how much forwarder have we got in the main and pressing business of purifying our rivers—as a consequence of clearer knowledge of minute forms of life?

Intermittent filtration.

The late civil engineer Bailey-Denton demonstrated, thirty years ago at Merthyr Tydvil, the best conditions of intermittent downward filtration, and his filters there and at Kendal, Abingdon, etc., are still doing their work efficiently to this day, while the coke, coal, clinker, burnt ballast, etc., beds, so popular of late, are clogging up after a few years of more careful treatment than was ever accorded to an acre of land under sewage.

Anaerobic action has also been proceeding in the old sewers of most towns and, as it has now been proved that there is no advantage in the exclusion of air, upon which Mr. Cameron laid so much stress when he brought his Exeter tank to public notice in 1897, there can be no novelty except its name attaching to the anaerobic or *septic* system, which has thrown many sanitary authorities off their balance of late years.

The whole modern system of self-cleansing sewers having been only rendered possible by public recognition of the horrible nuisance arising from middens, cesspools, and irregularly built sewers of deposit, it is hard for those concerned in the cleanly disposal of sewage to be told that because sewage works are usually remote from populous districts they must there put up with the cesspool nuisance and fancy its old smell changed by the new name, because a preliminary stage in the transmutation of sewage has not taken place, as was formerly the case in the sewerage system of some modern towns, before arrival at the works.

But in this as in other affairs there is force in the old maxim, *Medio tutissimus ibis*, and a properly constructed open tank, for simple deposition of the solids (frequently washed out), arrests most of the solids and allows fresh liquid sewage, after slight anaerobic action, to pass on to land or filter bed in a perfectly inoffensive condition.

The cleanly and dirty processes for sludge removal.

As an example of this I have, at Aldershot, a pair of tanks close to a public high road, one of which fills with sludge and is emptied every fortnight or so, and as a contrast there is another pair of larger tanks in a remote quarter of the same farm in use for years as septic tanks, from which some sludge is drawn off at long intervals, anaerobic action being allowed its full course as in the Exeter experiments.

It is interesting to compare the results of these preliminary clean, and dirty, processes respectively on similar *very fresh* domestic sewage which enters the clean depositing, and the septic tanks alike, and my observations are as follows :—

1. The manurial result in growth of crop *slightly* greater with the septic liquid.

2. Labour increased by the greater deposit carried on to the land under septic liquid.

3. The removal of sludge and washing out the clean tank gives an hour's work with very little smell ten yards to leeward of the site, but drawing off sludge from the septic tank is a very unpleasant operation, and, at all times, the vicinity of tank and carriers is malodorous for a radius of at least fifty yards from the septic tanks.

Loam on sand and gravel the best medium for aerobic organisms to work in.

Passing now to the aerobic stage of sewage purification we find it universally admitted, that a good loam resting on very porous sand or gravel, affords the best medium for work by the oxygen-loving nitrifying organ-

isms when they are supplied with constantly moving liquid sewage, and given intermittent periods for the aeration of the pores of the soil.

The proportion of sewage to land is of course as variable as the quality of the land itself, and the best sort of land is rarely available, while the improvement of natural land is not understood by the engineer or chemist, who are usually appealed to by sanitary authorities in their sewage difficulties.

Hence the variety of artificial substitutes of contact beds, costing from 5000*l.* to 12,000*l.* per acre, which have been proposed of late years, with the object of purifying a large volume of sewage on a small area.

Leeds experiments.

Mr. Dibdin first startled the world with the formula 1,000,000 gallons per acre, but that has long been cut down to 200,000 gallons, and the life of the contact bed has become the subject of serious concern, as shown in the annexed table of experiment at Leeds.

Others have sought to increase the proportion of sewage to area by arranging for *continuous* instead of *intermittent* application; but the difficulty of sprinkling so that every part of a bed may be kept just moist, in order that aeration may be continuous as well as the dropping sewage, is very great, and increases with every gallon and foot from the scale of a laboratory experiment to that of a practical working for a town's sewage.

There was an article published a few years ago in the Journal Royal Agricultural Society (England) on "The Making of the Land," showing how nearly all the value of agricultural land in England has been stored up in it by the exertions of our forefathers, through a process of successive improvements from, in many cases, worthless sand and clay, to a condition of the greatest fertility; and I often think that the 12,000*l.* spent at Birmingham

TABLE SHOWING THE VARIATIONS IN CAPACITY OF CONTACT BEDS.

—	No. 1 Rough Contact Bed.		No. 3 Rough Contact Bed.		No. 5 Rough Contact Bed.		No. 7 Single Contact Bed.		No. 8 Single Contact Bed.	
	Dates.	Gallons.	Dates.	Gallons.	Dates.	Gallons.	Dates.	Gallons.	Dates.	Gallons.
Original water capacity after putting in the coke . .	1897. October 1	83,300	1898. Nov. 21	51,800	1899. Feb. 28	53,100	1899. March 24	75,000	1899. March 23	29,500
After experiment .	1899. May 6	22,700	1900. March 10	14,700	1900. June 1	13,200	1900. October 20	21,600	1900. June 1	9,800
Duration of each of above experiments and loss in gallons	19 months	60,600	25½ mths.	37,100	15 months	39,900	7 months	34,100	14 months	19,700
Loss in percentage of original capacity .	73 per cent.		71 per cent.		75 per cent.		61 per cent.		67 per cent.	

N.B.—The average duration of the above experiments was 14 months, and average loss of capacity about 70 per cent. original water capacity in that period.—A. S. J.

or elsewhere on an acre of contact bed could be expended to better purpose in preparing 100 acres of the worst land to deal, for any number of years, with as much sewage as the contact bed may do for a few years. In the one case we know no limit to the life of the purifier, and that it must be a very short one in the other case.

Wrexham sewage farm.

At Wrexham, in North Wales, I had nineteen years' management of about 150 acres of good land, with a mixed residential and manufacturing sewage of some 15,000 population, with large breweries and leather works. The owner of this land at the termination of lease asked so exorbitant a price for the improved freehold, that the corporation decided to sacrifice the sewage works on his land, and to carry out a scheme of mine for carrying the outfall sewer two miles further to a site of 200 acres, which they could acquire on reasonable terms in the year 1889.

During my management there was no trouble about the effluent, although it was carefully watched by the authorities of the city of Chester, which takes its water supply from the river Dee, some twelve miles below my late farm ; and the fact that the scheme which took the Wrexham sewage two miles nearer to the Chester waterworks intake was carried out *unopposed* is, I think, strong evidence of well-founded confidence in the efficiency of land treatment where the public have the opportunity of observing such results. It is easy to get up a case with expert evidence against any sewage scheme where the land-owners, clergy and others have no means of properly informing themselves, and have a prejudice against sewage which it is very difficult to overcome except by giving the utmost possible publicity to the truth.

The Camp Farm, Aldershot.

Of late years, while working for the War Department, I have found it expedient to be more reticent, but the Camp Farm restoration has in one way or another become known to the public, and there can be no great harm in my now referring to the circumstances as neither martial law nor a censorship has yet been proclaimed in Hampshire.

When Aldershot Camp was first hutted, soon after the Crimean War, a certain Colonel Ewart, R.E., had imbibed true ideas of the separate system through his association with the work of the late Mr. Menzies, the Deputy Ranger of Windsor Forest, who preached and practised that system in the drainage of Windsor Castle and the town of Eton at a time when every other civil engineer scouted the possibility of keeping rain or subsoil water out of foul sewers—they said it was essential for flushing their big sewers.

Colonel Ewart, at any rate, impressed his corps, and after about 1866 one began to see the word FOUL painted up over gratings into which the soldiers were to pour their slops. A civilian, James Blackburn, also a friend of Menzies, was employed by the War Office to deal with the camp sewage on about 100 acres of rough heather-covered land close by, and he, knowing his business, watched what came down the sewers in wet weather and kept the Royal Engineers up to the Menzies standard.

Mr. Blackburn's successful management.

Together with this initial advantage of having a regular volume of sewage not much affected by storm water to deal with, Mr. Blackburn had many drawbacks in the "pan," as it is usually called, of iron conglomerate underlying the very irregular surface which was pitted all over with holes from which gravel or sand had been dug many years ago; but he persevered until he had

got nearly all the area to bear good crops, when he entered the Camp Farm in competition for the Royal Agricultural Society's 100*l.* prize in 1879 for the best managed sewage farm in the United Kingdom. The Report of the Judges at that competition is recorded in the Society's Proceedings 1880, giving full statistics except financial accounts, which Mr. Blackburn withheld because he was then in treaty with the War Office for new terms after fourteen years' work on the War Department Farm. My impression after reading the judges' reports and having seen the farm a year or two previously to its date, is that, if the condition as to the production of the financial accounts could have been fulfilled, the first prize would have been awarded to the Camp Farm instead of jointly to those of Bedford and to Wrexham.

Mr. Blackburn had built a big wooden shed and sublet it to a man who bought his ryegrass for some fifty cows (for whose milk there was a great demand in the camp), so this subtenant made a tempting offer to the War Office and got a fourteen years' lease of the whole farm, while Blackburn retired in disgust.

I wish to write only from knowledge of facts, and will therefore take up my narrative again in 1895, after an interval of some fifteen years.

Neglected state of, in 1895.

In the month of May 1895, I was called upon to visit the Camp Farm and report to Mr. Henry Campbell-Bannerman, the Secretary of State for War at that date.

I found the whole farm in a deplorable condition of neglected nuisance, stagnant lakes of sewage retained here and there by banks of earth, buildings and fences in decay, and the greater part of the camp sewage passing, by pipes laid by its tenant, under a road which

forms the lower boundary of War Department land, to some rough meadows held by their tenant from civilian owners for the purpose of saving him the trouble of spreading the sewage over the sloping surface of the War Department Farm—work which required the use of a land surveyor's level and staff.

In the ditches of these flat meadows the sewage could go through the septic process to its fullest extent as the level of the river Blackwater kept them nearly full at all times, and the supernatant liquid could spread over the coarse herbage of these meadows only in winter floods, with the result of heavy crops of hay, and sewage disposal conveniently out of sight and outside War Office jurisdiction when a Royal Engineer officer might come to inspect the Camp Farm from time to time.

British Medical Journal's report.

But before my visit an active Medical Officer of Health (Dr. Seaton), taking an interest in the state of the river bounding his county of Surrey, detected the camp origin of the stagnant sewage, and, concluding that the meadows must form part of the Camp Farm over the road, made a serious report about "Government Sewage Marshes," which the *British Medical Journal* took as a text for an article, and the Thames Conservancy attacked the War Department as soon as their 1894 Act gave them jurisdiction in the matter.

Temporary abatement of nuisance.

I was told that the Camp Farm milk and grass had been condemned, and that the tenant had consequently sold his cows and was to give up the farm on June 20, 1895; therefore my report was wanted *forthwith*, but it was only to take account of anything which could be done *temporarily* to abate nuisance, as an agreement was pending with the Aldershot District Council for the removal of the camp sewage outfall to some site, at least two miles distant from the camp, at which the District

Council was to become solely responsible for its future disposal, together with their own Aldershot town sewage, and the War Department to be rated for the purpose like any other householder.

I found the Commanding Royal Engineer then in office fully alive to the existing nuisance and prepared to support any efforts I might make to abate it. Accordingly I agreed to become manager in control of such labour and material as was necessary for immediate temporary improvement, and being supplied with army horses, and any necessary buildings, tanks, etc. to be constructed by the Royal Engineers.

1897. The War Office resolve on permanent improvement.

After about two years it became understood that the nuisance could be permanently remedied on the Camp Farm, as I had said from the first, and accordingly the draft agreement, which had then been in discussion for five years, was abandoned. I was asked to prepare a scheme and estimate for such permanent works as would enable the sewage to be effectually disposed of on the Camp Farm.

Recollecting that the sewage had to be at once cut off from Dr. Seaton's "Sewage Marsh," and its disposal provided for throughout on War Department land, it will be observed that the improvement work had to proceed piecemeal with some extra care and arrangement; but on the whole I am satisfied that the work has been completed with greater efficiency and economy than would have been the case if the sewage had been turned into the river and the whole site handed over to a contractor for two years in the usual course.

About the same date (end of 1897) about 13 acres of land was handed over to my management with sewage from the Royal Military and Staff Colleges at Sandhurst, about 8 miles distant from the Camp Farm, and, being

somewhat better land to begin with, this part now presents a very pretty example of what a small installation for about 1000 population may accomplish.

But it is worked as part and parcel of the Camp Farm, horses being sent out to Sandhurst from Monday to Saturday when required.

It is, perhaps, worthy of note that the reform of the Camp Farm was initiated in 1895 by the Secretary of State for War in a Liberal Ministry, and that it has weathered for seven years all the storms of Jingoism and the fashionable crazes for artificial sewage treatment.

Sir Redvers Buller's period of command at Aldershot.

But whatever may be the rights or wrongs of General Sir Redvers Buller's quarrel with the Press and the Government, his reputation as a practical agriculturist is undeniable, and while in command at Aldershot it was his custom to stroll over the Camp Farm on a Sunday afternoon, occasionally leaving a message with cowman or bailiff to warn me of anything he found amiss, for which I was very grateful, living as I do ten miles away. I am proud, therefore, to be able to publish the following letter from one who has shown that he is not to be influenced by complaisance to superior or inferior in expressing or modifying his opinions, and he writes as follows :—

17 Lowndes Square, S.W.
July 14, 1902.

My dear Jones,

I am delighted to hear that you are publishing a book about sewage treatment.

The sewage farms at Aldershot and the Royal Military College afford ample proof of what a sensible practical man can do. But it is not every one who knows what those farms were before you took charge of them, nor do I think that any one seeing them now could conceive their previous condition. It is to that I can testify; you have turned putrid sewage bogs into fertile fields. You will confer an immense benefit on the

country if, by your book, you can only teach sanitary authorities generally that the crux of the whole question is the necessity for practical commonsense measures against sewage stagnation, and if those measures are taken nature will do the work of purification without the assistance of expensive patents or artificial devices.

Yours very truly,

(*Signed*) REDVERS BULLER.

To COL. A. S. JONES, V.C., C.E.

It must not be gathered from the foregoing account that the War Office authorities are prejudiced in favour of the *natural* treatment of sewage, for, like many other sanitary authorities, they have been bewildered of late years by the numerous forms of "*artificial*" treatment in vogue, and I know of more than one experimental installation for barracks where good available land has been neglected, for I read last summer of ghastly failures among the bacterial arrangements in some of those.

Success mainly due to activity of farm bailiff, foremen and other workers.

I cannot quit the above account of the vicissitudes of the Camp Farm in fourteen years' growth from a sandy waste to a condition which tempted a tenant to pay a rent of 3*l.* odd per acre in 1880—its retrogression to its primitive waste during the following fifteen years—and restoration to its present measure of fertility, without expressing the belief that Mr. Blackburn's success and my own have been mainly due to our good fortune in obtaining the willing services of excellent intelligent foremen and workers who, one and all, have taken a real interest in their several tasks.

Mr. Cameron and other engineers may boast of their labour saving (?) automatic appliances for opening and shutting valves on sewage works, but practical workers, responsible for dealing with a million gallons a day and

upwards average, in hourly varying flow of town sewage, will agree with me in hesitation as to placing entire confidence in the substitution of automatic machines for any large proportion of their manual labour.

Education and encouragement of sewage employees advocated.

I have for many years advocated education of sewage farm managers and watermen, to be selected from the rapidly decreasing class of agricultural labourers by the tender of high wages, houses and good gardens, with other profit-sharing allowances which it will well pay sanitary authorities to hold out to their sewage employees.

In this sense I am glad to note the recent formation of "*The Association of Managers of Sewage Disposal Works*," Secretary, Charles H. Ball, 5 Fetter Lane, London, E.C., as a Trades Union move from within well calculated to raise the status of the class of men upon whose exertions the community must mainly rely if there is to be any hope of improving the condition of our streams and rivers.

Evidence and Reports of Lord Iddesleigh's Royal Commission.

Two large Blue Books containing the evidence taken by Lord Iddesleigh's Royal Commission have been published since the Interim Report, and their contents more than warrant the opinion expressed in the latter; indeed it must surely be admitted that the case for each of the artificial systems was very fully gone into before that Commission expressed the guarded conclusion, "We doubt if any land is entirely useless."

I do not believe that the surface purification obtained by distribution over even the densest of clay lands was *effectively* put in evidence, and too much weight was given to the difficulty of increasing the effective top soil on such land; but on the whole I think that the Interim Report is very satisfactory to the reasonable advocates of a preference being given to the adoption of a large area

of land, where available, over any artificial treatment on a small area, other things being equal.

At the time when the Interim Report was issued, however, a very full and careful examination of a select number of sewage farms was still in progress, and Appendix 22, with a casual mention by Dr. M'Gowan, affords the only glimpse to be had in the bulky Blue Books, of any results of that examination having been as yet adduced in evidence.

The Commission's officers, to my knowledge, were engaged for many months in examining, surveying and taking numerous samples of sewage and effluent at the Camp Farm, and, as they doubtless had equal opportunities of independent observations on the other selected sewage farms, the further reports of Lord Iddesleigh's Royal Commission cannot fail to be interesting and instructive.

On one point Appendix 22 to the Blue Book abundantly supports an opinion I have so often expressed, namely, that a good strong loamy surface is a more efficient purifier of sewage than many feet of barren sand.

I refer to the curves in Appendix 22, showing the greatly superior purification effected at Nottingham with the best soil as compared to that of the sandy one at Aldershot, which, in its natural character, is about the worst for purification and for producing crops to be found in England.

My experience, however, all points to the extreme importance of studying local conditions from the first inception of plans in each particular case, to their completion with the best available materials.

But when the engineer has done his best, the sanitary authorities, having borrowed the funds to pay for the work, will take no further trouble about its sewage, and

will often engage careless ignorant workpeople at inadequate wages to carry on the hourly varying labour, on efficient performance of which success depends.

Automatic appliances for sewage and effluent discharge.

It may seem idle to complain of boards and their employees showing little interest in the work of sewage disposal, but it is worse to pander to their failings by selling them automatic machines under the pretence that all the thought, and fertility of resource, required for efficient sanitary sewage disposal can be supplied by ingenious applications of hydraulics on the principle that sewage is a fluid, and, as such, will behave like clean water.

Of course, when the aerobic treatment is carried out on a bare level surface of cinders or coke growing only weeds, the lack of interest is very excusable, but in the natural system the growth of crops and contouring a sloping surface with carriers so that every part shall have its trickling water alternating with dry periods for cutting the crops or hoeing out weeds, should be a matter of constant interest to an agricultural worker, and, if he knows his business, good crops and purity of effluent must go together.

Managers should have a free hand.

In order to attain this happy result, a manager must know his business and be given a free hand, not pestered by members of a committee (farmers, butchers, gardeners or town tradesmen) coming to give their advice or orders. The river authority should take samples as often as they like and send the manager as soon as possible the analyses with day and hour of sampling as a guide for future working.

He will then have to explain any defect from average purity of effluent, due to one of the hundred contingencies which may arise in practice, after he and the river authorities have agreed about what that average

analysis should be for his particular farm or works; and it will be for the advantage of all parties not to try and enforce a fixed standard for a whole district, as some river authorities usually attempt to do, because it is easier to lead than to drive a good manager, and nothing at all can be done with a bad one.

It must not be supposed that I think river authorities should be easy going, quite the contrary, but they should trust their inspectors' reports, and "run in" those sanitary authorities who are careless about the management of their sewage farms and trying to cut down working expenses and capital.

In precipitation or other artificial sewage works it is easy to judge this, but more difficult for any one except the good farm manager to know whether the land is being made the most of for profit or for purification; still the rivers authority ought to get to know if they and their officers take pains.

Purification and profit.

It is a common idea that working a sewage farm for profit, and for purification of the sewage, are two incompatible things, whereas, the good manager with sufficient working capital (double or more what would be enough for the same acreage in ordinary agriculture) and a good market for produce will attain the two together in due proportion in all ordinary seasons, when a fair allowance has been made him for the necessary sanitary work.

It is easy to see how the popular idea of incompatibility has arisen in a case like that above stated of the Camp Farm tenant, eating up year by year all the fertility stored up in the land during the previous period, and letting nearly all the sewage run to waste, because its scientific application would cost much in thought and labour. In much the same way district councils have been, all over the country, stinting their labour bills and

interfering with their managers' purchases and sales in order to make as small a demand on the rates as they can—each year bringing some change of system—to the end that nobody is responsible or has any confidence in master or man.

With such a state of things up and down the country the way was prepared for preachers of microbe agency to say, why should you buy all that land when a septic tank, a few acres of coke or burnt ballast, and a patent automatic opener and shutter of valves (which you see working so nicely with tap water and model at some exhibition) will give you "no more troublesome sludge," and a first class effluent with hardly any labour bill? if you only agitate against that arbitrary Local Government Board, which insists upon land!

But those gentlemen neglected the fact, that in a few years' time their filters would have to be pulled to pieces, washed and put back, while the land remains as efficient as ever, and a valuable asset, in some cases saleable at building value, if it becomes desirable to move the outfall further at some future time.

Sludge treatment.

In the above comparison between natural and artificial treatment reference has been had chiefly to the aerobic branch of the business, but the anaerobic, breaking down *some* of the solid organic matter and the sanitary disposal of the remainder in the state of sewage sludge (containing fully 90 per cent. of moisture) must not be overlooked or shirked as beneath the attention of the scientific bacteriologists and chemists whose analyses of effluents, and often of what they call crude sewage, are made from the liquid which has passed through a filter paper in their laboratory before their "oxygen absorbed" or "ammonia processes" are proceeded with.

On the contrary, I have always maintained that

sludge, being the foulest part of town sewage, ought to receive primary and earnest attention if we desire to improve the condition of our watercourses.

When town sewage is pumped through a long rising main, it can often be spread on the land in its really crude state, and if the soil is clay ploughed up to receive it the sludge is most beneficial to its texture.

But in every other case we must face the nuisance of extracting the sludge, and its desiccation in one of the following ways.

1. On a farm at some distance from roads and houses, the cheapest plan is to form a bank of earth about 18 inches high, enclosing a rectangular area into which the wet sludge can be run or pumped out of depositing tanks, and left alone until dry enough for cartage, when it can be used on the farm or sold to neighbouring farmers for a shilling or two a load.

2. A wall of farmyard *long* manure may be used instead of earth, and trench 5 feet wide dug on each side of the longer sides of the rectangle, leaving 3 feet of ground between the wall and trench, on which men can stand to scoop the sludge over the wall when it has consolidated a little in the trench; the latter is then ready to receive the sludge from another tank emptying, which is again scooped over the wall on to a thin coating of farmyard manure, which has been scattered over the last layer of sludge in the rectangle; and thus in a year's time a solid mass of the mixture is raised four or five feet high, and is in capital order for putting in drills for a crop of mangold wurtzel.

This is the plan in use at the Camp Farm; it occupies little ground and smells only like rotten dung does during the few days carting to the mangold field.

3. Pressing by compressed air forcing a liquid mixture

of sludge and lime into the interstices between cloths supported by vertical iron plates on a horizontal frame; and such pressing is a very expensive process, only resorted to when the sewage works are in a confined populated district where no accumulation of sludge can be tolerated.

Expert examination of neighbourhood a very necessary preliminary to any sewage scheme.

Before any sewage scheme is conceived a very careful survey of the neighbourhood ought to be made by a person who knows the requisites of a site for sewage disposal, especially if land irrigation is intended, because natural advantages of site both for tanks, main carriers, roads, etc., may make all the difference in the world in expense and efficiency not only in first cost of works but also in their use afterwards.

And if land is to be acquired for sewage farming it will be very desirable to include in the purchase some neighbouring high lying area, not required for sewage disposal but for growing straw crops to be used on the farm.

Cropping a Sewage Farm.

Vegetation of some kind, useful or weeds, *will* grow from sewage, and must be frequently removed from land or contact bed.

This is a matter of vital importance, because when sewage is *intermittently* applied to land of any kind or to coke beds, vegetation of some kind or other must result and must be removed in order to leave a clear course for the next dose of sewage; the cost of removal and destruction of weeds will be found very great when contact beds are tried on any working scale and would be quite prohibitive if allowed to grow on irrigated land.

Hence we must crowd out the weeds as much as possible by useful plants which will bring something towards the cost of their removal; and as that return from perishable greenstuff is dependent upon its

immediate sale or consumption on the farm, the manager must cast about for demands for his abundant supply; but as both the sunshine (in this climate) and markets are very capricious factors in the problem, he has no easy task always to make both ends meet.

Theoretically the town which yields the sewage ought to provide an abundant demand, but in practice it can rarely be depended upon, Edinburgh being the only exception, where the Craigentinny sewage meadows are rented at a very high figure by the cow-keepers of a city situated in the heart of an arable district.

Alternative destinations for vegetation thus removed. Milk (everywhere in demand) or a destructor furnace.

Fortunately, however, there is always an unlimited demand for milk, and if he has the means of keeping a herd of cows on the farm, or can arrange with a neighbouring cow-keeper to take all the grass and roots he can supply at a low rate, it is about the best course a manager can adopt.

If he maintains a herd of cows, tied up in good, well ventilated stables, and has them daily brushed and groomed like horses, they require no exercise and produce milk in perfection for an average period of fifteen months from date of purchase after their third or fourth calving.

Such a herd will consume rye-grass carted from the field from April to November, and mangolds, kohl-rabi, and rye-grass hay during the winter, thus securing a uniform demand for produce of the sewage land throughout the year, and such cows will only require a little cotton cake and oat straw bedding (of which latter they eat a good deal) to fit them for sale to the butcher as soon as they become dry.

The advantage of such a steady demand is so great when rye-grass and mangolds, etc., are indicated as the

main crops of the farm, owing to the large volume of sewage per acre, that the system of cow-keeping is forced upon managers, however reluctant their sanitary authorities may be to provide the necessary working capital, unless they can find a reliable contractor to receive at a fixed price any quantity of grass and roots the authority may grow and deliver.

Permanent pasture grazed and for hay available in certain cases.

When a town has more land in proportion to its sewage, permanent pasture may take the place of Italian rye-grass, and, with proper precautions, a part of the permanent pasture may be grazed; but the saving of labour, thus supposed to result from letting animals bite and carry their food, is expended in making up, in a necessarily imperfect manner, the carriers trodden in by the cattle.

Importance of neat tidy contour carriers, correctly levelled.

And here I would observe that most of the bad odour into which sewage farming has fallen of late years is distinctly traceable to the common absence of sufficient regularly contoured and neatly cut distribution carriers resulting from parsimony about wages bills natural to the ratepayers' representatives in Council, and often to the manager's dependence on a borough surveyor's coming to the farm with his level and staff for great measures, or on his own guesses for smaller works, instead of using an instrument to peg out every distribution carrier at the right moment.

Attract good labour.

There is another important outlay of capital to be provided for in every complete sewage scheme, which should embrace sufficient good labourers' houses and gardens in order to attract and retain on the spot the best class of workers.

Summary of the experience of a lifetime.

To sum up the general conclusions to which my experience points, and which I trust may prove useful to district councillors, they are as follows :—

1. In works of sewerage, limit and regulate, as far as possible, the volume of sewage by excluding subsoil water and clean surface water.

2. Where the outfall sewage enters the disposal works provide a pair of open catch-pits (or grit-chambers), each twice as wide as, and 2 feet deeper than the sewer, with sluices allowing the sewage to pass through one pit at a time in its free course, while the other pit is being dried and the deposited detritus dug out. The depth below sewer invert may be more than 2 feet, and length of catch-pit is immaterial, but I confine its width to twice that of the sewer in order to conserve sufficient velocity in the current to carry forward organic matter, paper, etc., and leave only clean sand and gravel in these catch-pits.

Continuing the course by open channel (of same width as outfall sewer), it should expand to five or six times its width, forming the screening chamber, and thence discharge into the

3. Depositing tanks. These are best formed in concrete with smooth surface, with a semicircular level weir from which the liquid overflows into a semicircular collecting open carrier leading to the aerobic process on land or contact bed.

The semicircles above referred to are struck from centre of the inlet to depositing tank with a radius of 50 feet or more.

The weir level should be at least 1 inch below that of invert of inlet, and the depth of tank immediately under this point should be governed by consideration of the facility of drawing off the sludge by valve at that depth to the sludge drying beds by gravitation if possible, or pump if necessary, and

from this sludge emptying valve the smooth concrete bottom of tank slopes up to the semicircular weir above described.

The bottom and sides of such a tank should be made with the best Portland cement and finest granite chippings wrought to a smooth surface, so that the sludge may be easily swept clean away with a squeegee to its outlet valve, as it is very necessary to have the tank thoroughly washed after each emptying if my view of the *clean* mode of sewage disposal is to be carried out.

But with the dirty mode, on the contrary, some of the sludge only should be drawn off and the septic anaerobic action preserved continuously in the tank itself, whereas I prefer that action to have its early and less offensive course in the tank and its completion in a drying bed mixed if possible with farm-yard manure.

4. The aerobic process. The one essential point in this final process, whether in land or "contact beds," is *sufficient* aeration (excess as by blowing has no result commensurate with cost of its introduction), and it can be attained by intermittence of sewage and rest, or by continuous passage of sewage through a bed of coarse medium *kept always just moist in all its atoms* by a rain-like dropping on the surface so carefully adjusted as to moisten all parts and not to form a water-seal in any part of the bed. Intermittence is easily arranged on any scale of working, and continuous filtration, on the contrary, is difficult even for a few thousand gallons a day.

Anticipation of a coming reaction against

Since the above was written our grand old philosopher Herbert Spencer has published a volume of

"fads" and over-pressure in sanitation.

"Facts and Comments" * containing a chapter on "Sanitation in Theory and Practice," which points to a coming reaction against the movement begun, some fifty years ago, by the late Sir Edwin Chadwick and followed up by many enthusiastic exploiters of the popular dread of "germs," which he associated with bad smells.

Of course the professor's practical acquaintance with Chadwick's hobby is, as he says, very limited, and his argument, that because sewage and manure smells are harmless in the open air of the country, they should be equally innocuous in a town, falls to the ground when brought to the test of experience, and I trust that Mr. Spencer will forgive me for pointing out that sewer-gas, drawn into a dwelling room, in town or country, through scullery waste pipe or other connection with a sewer in which the air is of lower temperature than that of the dwelling room, is really prejudicial to health whether accompanied or not by disease germs.

And although, as one of the experts to whom Chadwick appealed and whose moderate testimony was cast aside because it did not come up to the standard desired by his enthusiasm, I fully endorse Mr. Spencer's caution with regard to the mass of Blue Book evidence on sanitation, I venture to express my regret that the dear old man has had an unfortunate experience of sewage treatment, and my surprise that so deep a reasoner should have published his judgment in this chapter without having taken the pains to extend his acquaintance with sewage treatment in other places than the single instance of Burton-on-Trent.

In thus despising an unsavoury subject Mr. Spencer is not alone, and I am sorry to have to say that general

* 'Facts and Comments,' by Herbert Spencer. Williams and Norgate, London, 1902.

indifference is answerable for the waste of much public health and money, because it need not be surprising if those following a *despised* trade are sometimes ready to take advantage of the prejudice and ignorance of their employers.

In this sense I beg to quote Professor Spencer as follows in justification of the reflection with which I began the above essay :—

"New sanitary appliances are continually being devised, sanctioned by authority, and required by surveyors ; and surveyors may have and certainly sometimes do have, personal interests in pushing the use of them ; either as being shareholders in the companies they are manufactured by or as receiving percentages on the numbers sold through their recommendation."

NATURAL AND ARTIFICIAL SEWAGE TREATMENT.

By H. ALFRED ROECHLING,
M. Inst. C.E., etc.

I. INTRODUCTORY REMARKS.

At the request of Lieut.-Colonel A. S. Jones, V.C., Assoc. M. Inst. C.E., who has done yeoman service in this matter, I have great pleasure in putting down some observations on this old but ever controversial question of sewage treatment.

Colonel Jones has done more than anyone else living to establish correct views on sewage farming, and he has lately changed the Government sewage marshes at Aldershot into a veritable "Garden of Eden," watered by the waters from Aldershot Camp, growing healthy crops, and causing not the slightest nuisance. After many struggles, even the milk from the dairy cows is now recognised as good and supplied to the military hospitals. This is an achievement of which anyone might be proud ; and all those who have been over the farm during the time of the "deluge," and can now study the order and system evolved out of chaos by Colonel Jones will testify to this ! It is pleasant to record that the War Office have recognised Colonel Jones' work for them by having appointed

him quite recently to manage all the sewage disposal works in the Aldershot district. This will involve the laying out of irrigation works in eight separate places, in some of which artificial methods of sewage purification have been tried and found wanting.

Before commencing with my task proper it may not be out of place to describe here very shortly the various stages through which the sewage question has passed during the century just closed. Such a retrospect is of general interest and may throw some further light upon our subject; it must of necessity be short, otherwise it would absorb more time and space than is at my disposal, and any shortcomings in this respect that the reader may discover, I trust he will kindly put down to this cause.

"The man in the street" seems year after year more called upon to form an important element in settling questions even of a scientific nature, and if what I am going to say should prove of some service to him my labours will be well repaid.

II. THE SEWAGE QUESTION DURING THE LAST CENTURY.

A Short Retrospect.

In dealing with the sewage question during the last century, it will be an advantage to distinguish between the theory and practice of sewage purification, as such a division of the subject will render it less complicated and will tend to avoid misconceptions.

Dealing first with the theoretical side of the question, it is very doubtful whether at the dawn of the century even a working hypothesis existed to explain the process

of sewage irrigation which was then adopted in one or two instances, notably at Edinburgh, where the town sewage was very successfully purified on the Craigentinny meadows. It is more than likely, that at this time instinct took the place of theory, and that sewage irrigation was an instinctive imitation of irrigation with river water employed for many centuries in some eastern countries.

Later on it is on record, that Cagniard de la Tour in France, about the year 1825, and Schwann in Germany, about the year 1836, expressed the view, that organised substances—micro-organisms—played some role in fermentative and putrefactive changes. Almost diametrically opposed to this were the views authoritatively laid down by the then star in the chemical horizon, Justus von Liebig, who, about the year 1845, maintained that these changes were brought about by the dead inert matter itself—by molecular movements in the same—and not by organised substances, the presence of which in fermenting or putrefying substances was purely accidental. So great was Liebig's authority then, that many almost blindly adopted his views, and the strife that commenced around these opposing views was fought with the greatest bitterness. But the stronghold of old ideas, which were gradually but surely being supplanted by new ones, could not hold out for ever against combined attacks, however stoutly it was defended by its designer, and its final downfall came about the year 1860, when a young Frenchman, Pasteur, established beyond doubt by his ever classical researches, that fermentation and putrefaction were, in the first instance, due to living organisms and not to dead matter. Pasteur further demonstrated that living organisms were also the cause of some and probably of all zymotic diseases.

So far, so good! But unfortunately the methods of biological research employed by M. Pasteur were very cumbersome and left otherwise much to be desired, so that his discoveries could not be fully utilised and extended, until in 1882 Robert Koch of Berlin published his new methods of investigation. This was the signal of raising the floodgates of biological (bacteriological) research throughout the world with this result, that the flood waters pent up until then inundated practically other branches of scientific investigation and drowned their individual life for some time to come.

During this interval, 1860 to 1882, investigators who wished to study the organised impurities in sewage had to proceed by indirect methods. They had no means of ascertaining by direct biological experiment the number and character of the micro-organisms contained in sewage: all they could do, was to determine chemically the dangerous nature of the sewage by the amount and origin of organic matter it contained, which would probably act as food to the germs; and the greater this amount was, so it was inferred, the greater would be the number of germs it harboured and the more dangerous its character.

This was the condition of things at the time the second Rivers Pollution Commission carried out its investigations, which in many respects, and rightly too, are still considered standard investigations. It cannot be surprising, therefore, that, being without proper means of biological examination, and having to rely chiefly on chemical methods only, the Commissioners came to the conclusion that the changes brought about in sewage purification were due to mechanical and chemical agencies!

It is frequently a matter of the utmost difficulty to

ascribe, after the lapse of half-a-century, a new theory to one special author, as several investigators may have been trending the same way quite independently of each other, but may not have been equally successful in the matter of their publications becoming generally known. Theories, as a rule, do not drop out of the clouds like meteorites, they force themselves gradually upon men's minds and are elaborated by them until ripe.

Bearing this in mind, and subject to further research, it would appear as if Alexander Müller had been the first to apply Pasteur's general theories as to decomposition, fermentation and putrefaction to the problem of the self-purification of sewage. He made his experiments in 1869 and published them in 1873. Since that date a very large number of investigators have been at work on similar lines, and whilst it would lead too far to deal with them minutely, it ought to be stated that the results of their labour confirmed the view of living organisms playing a very important part in the decomposition of sewage. Among the many names prominent in this respect are those of Schloesing, Müntz, Hatton, Warrington, Sorby, Winogradsky, Percy Frankland, Dupré, Emich and Dibdin. That set of researches, however, which has done more than any other to consolidate the theory of bio-chemical changes taking place in the self-purification of sewage are the investigations of the Massachusetts State Board of Health, which were commenced in November 1887, and are still being continued.

Since 1895 a large number of additional experiments have been made, which will be dealt with more in detail later on, but speaking generally they have not materially increased our knowledge of the processes taking place in sewage purification.

Summarising the remarks on the theoretical aspect of this question, it may be said that, as to the agencies at work, we know now they are of a mechanical, chemical and biological nature; but as to the processes and products brought about by these agencies we know very little beyond the initial and terminal stages, as will be pointed out in some of the subsequent observations.

Directing now attention to the practical side of the question, it has already been stated that the only known sewage treatment at the commencement of last century was land irrigation. Then about the middle of the century chemistry seems to have taken the matter in hand and tried to make a lucrative business out of it. It is on record, however, that it did not succeed in this attempt, and the financial loss which this endeavour has caused is a dismal subject to investigate.

There is before my mind's eye the case of a gallant officer of His Majesty's land forces who, after having reached very near the summit of his career, retired and employed his time in trying to make a fortune out of sewage. So enamoured was he of the subject, that—so the story goes—he commuted his pension to have all the more ready money; but fortune did not smile on him, and his last days were spent under the lengthening shadows of the sorrow of financial difficulties, having practically lost all he possessed.

The emphatic verdict of the first Sewage Commission of 1857, the first and second Rivers Pollution Commission, and, indeed, of all other authoritative investigations, was in favour of land treatment; and it cannot, therefore, be surprising to find that the Local Government Board insisted, save in exceptional cases, that "any scheme of sewage disposal, for which money is to be borrowed with

their sanction, should provide for the application of the sewage or effluent to an adequate area of suitable land before it is discharged into a stream." Indeed, had this body taken any different view and neglected the findings of practically all authoritative inquiries, it would have been singularly deficient in the discharge of its duties to the ratepayers of this country.

But the best of land cannot go on for ever doing its duty if by systematic neglect and ignorance the essential conditions for successful purification are year after year violated ; and the great pity is that the Local Government Board, after deciding in favour of land treatment, did not systematically superintend this operation. It may not have had the power, but it is quite evident that had it done so, things would not have drifted from bad to worse, until local authorities, driven to despair by the apparent failure of land and not discerning the right cause, refused altogether to be ruled by what seemed to them a very unfair and absurd restriction.

It was at this time that Mr. Dibdin, who, on behalf of the London County Council, had been carrying out a set of valuable experiments, came forward with his application of well known theories to sewage operations on a large scale. As I pointed out at the time, Mr. Dibdin's experiments proved beyond a doubt that the application of sewage to suitable land was right in principle and that the failures were brought about by the non-observance of the rules laid down by this gentleman —that, in fact, sewage irrigation was the only natural method of sewage purification and that all the other methods were artificial. I described land treatment as the natural self-purification of sewage and the oxidation or contact bed system as the artificial self-purification of sewage.

But the swift current of public opinion had set very strongly against sewage farms, and nothing but the contact bed treatment would do. A large number of experimental plants on this system grew up like mushrooms all over the country, and the waves of enthusiasm seemed at one time to engulf even the Local Government Board itself with its "antiquated notions," until Parliament came to the rescue and appointed on May 7, 1898, a new Royal Commission to study the question of sewage purification.

This Commission consists of nine members,* i.e. six professional men and three laymen. Of the professional men, one is a biologist, one a chemist, two are medical men in administrative positions, and two are engineers likewise in administrative positions. Of the laymen two are members of special boards for the prevention of the pollution of rivers.

So far the Commissioners have issued an Interim Report dated July 12, 1901, a volume of evidence and a volume of appendices. Quite lately, it is stated, they have issued a further Interim Report, to which are attached separate reports on some special subjects by their officers, but this report has not yet come to hand.†

At the time of their first Interim Report, July 12, 1901, the Commissioners had held altogether thirty-five sittings, the first of which was on June 22, 1898, and the last on May 22, 1901. The period thus covered is nearly two years, and out of the thirty-five sittings thirty took place in London, and five in the provinces, viz. at Leeds, Ripon, Manchester, Accrington and Reigate.

* Two of these have since retired.

† This report has just been issued (August 18, 1902), and although the special reports it contains are of the greatest interest, it is not necessary to refer to it again in these observations.

On these occasions, all in all, fifty-eight witnesses were examined, who may be grouped as follows :

1 Zoologist	7 Medical men.
1 Botanist	11 Patentees
2 Laymen	14 Chemists
3 Bacteriologists	14 Engineers
5 Lawyers	

58 witnesses in all.

Out of this number twenty-five were officials, viz. five lawyers, six medical men,six chemists and eight engineers. Four officials were further managers of artificial sewage purification works, but not one single manager of natural purification works, i.e. a sewage farm manager, was called, the term "sewage farm manager" being used here to indicate an official whose sole duty it is to manage a sewage farm.

The entire absence of this latter class of official is so striking that it cannot be due to accident, but must be the outcome of a settled policy not to reopen questions conclusively settled by previous inquiries.

Another point that strikes the observer is that the Commission only called one zoologist and one botanist, as it is to these scientists that belongs in the first instance the question of studying the fauna and flora of sewage before the subject is taken up by other branches of natural science.

Speaking on the whole, the evidence taken by the Commissioners forms very interesting reading, and ought to be carefully studied by those who have to deal with the subject. When now and again opinions are expressed, which seem directly opposed to each other, it must be borne in mind that here, as in other things human, unanimity of opinion, though much desired, is apparently unobtainable.

To understand the conclusions fully, at which the Commissioners in their Interim Report have arrived, it ought to be pointed out that they had either to accept the recommendations in favour of land passed by all previous Royal Commissions and authoritative inquiries, or they had to show by incontestable evidence that their predecessors had made grievous mistakes, and where!

Of these two courses, the present Commissioners have adopted, no doubt for very good reasons of their own, the first, and they have started therefore, in the conclusions to which they have come, at the point where previous inquiries had left off, viz. that land treatment is a very proper method of sewage purification.

But before referring more in particular to their observations on land treatment, it will be necessary to point out that the Commissioners evidently divide all methods of sewage purification into two main classes, viz. natural and artificial methods. Into the former they only place land treatment, whilst they call all other methods artificial.

This division seems to have given a great deal of offence to all those who have expressed decided and frequently very one-sided views in favour of the "bacterial" treatment of sewage; but on closer examination it cannot be denied that the Commissioners were quite right in forming this view, as the following remarks will show.

For main divisions of all methods of sewage treatment two factors seem to be of primary importance, viz. the agencies which bring about this purification, and the way in which these agencies are employed. Now, it will not be denied that all agencies are natural ones, whether the process employed is a purely chemical one, a purely "bacterial" one, land treatment pure and simple, or a combination of these, and, at the present time no such

thing as an artificial agency is known; indeed, it is perhaps not too much to say that there cannot be such a thing as an artificial agency. Hence it is impossible to divide sewage purification methods in this respect by the agencies employed, and one is bound to fall back upon the way in which these agencies are employed. Here it is no longer open to argument whether a chemical process or the contact bed system—oxidation bed system—is artificial, or whether the land treatment is natural! For who would deny that masonry or concrete tanks and the materials contained in the same are artificial products—i.e. products formed by man—and that land is a natural product—i.e. formed by nature—and that further the soil is the natural home of bacteria. Hence it must be perfectly clear, even to a casual observer, that the line of demarcation drawn by the Commissioners between all known systems of sewage purification is a correct and legitimate one, and that all objections to such a division are based on misconceptions.

Concerning land treatment, the Commissioners observe, "We doubt if any land is entirely useless," but further on they observe that peat and stiff clay lands are generally unsuitable for the purification of sewage. Concerning peat, nobody acquainted with the subject would probably differ from their conclusions owing to the great amount of moisture contained in this material; but as to clay soils, the Commissioners when making this statement must have known that there are several successful sewage farms on this kind of land in existence, such as the sewage farms at South Norwood, Wimbledon, Warwick and Leicester, not to mention others. In the case of Leicester, although the land is a very dense boulder clay, the Corporation of this town have just purchased the freehold of the farm for about 160,000*l*.

Dealing with the artificial processes from a chemical point of view, the Commissioners are of opinion that it is practicable to produce by these processes alone, either from sewage or from certain mixtures of sewage and trade refuse, effluents which might be discharged without fear of creating a nuisance, and that in consequence the Local Government Board would be justified in modifying, under proper safeguards, the present rule as regards the application of sewage to land.

The artificial processes referred to in the observations appear to be the following :—

Closed septic tanks and contact beds.

Open septic tanks and contact beds.

Chemical treatment, subsidence * tanks and contact beds.

Subsidence tanks and contact beds.

Contact beds alone.

Closed septic tank followed by continuous filtration.

Open septic tank followed by continuous filtration.

Chemical treatment, subsidence tanks, and continuous filtration.

Subsidence tanks followed by continuous filtration.

Continuous filtration alone.

The Commissioners do not say what these safeguards are, in fact they state that no general rules concerning them can be laid down, and that in the case of these artificial processes it is necessary to consider every case on its own merits.

The next point dealt with is the bacteriological quality of effluents, and here the Commissioners observe : "We find that, while in the case of effluents from land of a kind suitable for the purification of sewage there are

* The expression "subsidence tanks" is intended to denote tanks which are used in such way that little or no septic action is produced.

fewer micro-organisms than in the effluents from most artificial processes, yet both classes of effluents usually contain large numbers of organisms, many of which appear to be of intestinal derivation, and some of which are of a kind liable under certain circumstances at least to give rise to disease."

No particulars of effluents from sewage farms are given, and later on it will be shown that this conclusion of the Commissioners is not in accord with the results published up to now and available concerning the bacterial purity of effluents from land treatment.

The report concludes with some remarks on rivers pollution. The Commissioners state that it is of the utmost importance to provide the simplest possible means for adequately protecting all rivers, and they think that this subject is of such grave importance "as to demand the creation of a separate Commission or a new department of the Local Government Board, which shall be a supreme Rivers Authority, dealing with matters relating to rivers and their purification, and which, when appeal is made to them, shall have power to take action in cases where the local authorities have failed to do so."

Summing up the observations on the practice of sewage treatment, it may be said that as a result of their extended inquiries, the present Royal Commissioners have at the end of the century re-established land in its position as the first and only natural method of sewage purification, beside which they have recognised artificial (biological) treatments as being under proper safeguards admissible for the purification of sewage.

Before concluding this portion of the observations, it is necessary to mention the valuable work done by Mr. Scott-Moncrieff and Mr. Cameron, who, contemporaneous with Mr. Dibdin, but quite independently, had

experimented with sewage and evolved their own artificial methods of sewage treatment.

These remarks must suffice for the more historic portion of the subject, viz. the progress of sewage purification during the last century, and it is time now to direct attention first to natural and afterwards to artificial sewage treatments.

III. THE SUBSOIL.

General remarks on subsoil and its properties.

Before dealing more in detail with the processes taking place in the pores of the subsoil of sewage farms, it may not be out of place to make here a few general observations on the mechanical structure of soil, its permeability, water capacity, retentive power, the capillary movements in the same, its temperature, the subsoil air, the movement of water in and through the same, the micro-organic life in soil, and its absorbing powers.

1. Mechanical Structure of Soil.

Size of grain and pores.

Here is of interest the size of the grains or particles composing the soil, the size of the pores and their collective capacity.

According to the character of the soil, its grains or particles will vary from very large in coarse gravel to very fine in fine sand and clay.

Variable size of pores.

The size of the pores will vary as the size of its grains from large to small, but frequently a certain kind of soil will contain a mixture of large and small pores. The finer the pores the more energetic will, as a rule, be the surface attraction of the grains composing the soil.

Surface attraction.

Pore-volume.

With particles of equal size pore-volume amounts to about 38 per cent. of the total space, and sinks down to 10 or 15 per cent. with particles of unequal size.

With equally sized particles the pore-volume is the same whether the particles are small or large.

The collective capacity of the pores or the pore-volume mainly depends on the equal or unequal sizes of the particles. When the same are of equal size the pore-volume amounts to about 38 per cent. of the total space occupied by the soil, but when this is not the case it may sink to as low as from 10 to 15 per cent. of this space. With equally sized particles the pore-volume is the same whether the individual particles are large or small. In nature it will be the exception to find all the particles of equal size, such a condition of things prevails only when careful sorting by sifting or riddling has taken place, and in the majority of cases the larger pores will be partly filled up by the smaller particles of the soil.

2. Permeability of Soil.

Permeability depends first on the size of the pores, and secondly on the pore-volume.

The permeability of a soil for the passage of air and water depends, in the first instance, on the size of the pores, and is further to some extent influenced by the pore-volume.

Effect of large and small pores.

Soil with large pores will offer but little resistance to the passage of air and water, but when the pores are small these movements will be greatly impeded.

Permeability is proportional to the fourth power of the pore-diameter.

It has been ascertained that the permeability of soils is proportional to the fourth power of the diameter of the pores, so that it decreases very rapidly with the diminishing size of the pores.

In frozen soil permeability decreases rapidly.

In subsoil with small pores all movements of air practically cease when it is half full of water, and in frozen soil the decrease of the permeability is still more marked.

3. Water Capacity of Soil.

Water capacity is equal to the pore-volume.

The water capacity of a soil is that quantity of water which can be stored in its pores; it is therefore equal to

the pore-volume. For very accurate measurements allowance must be made for a small amount of air, which even after filling remains in the pores and cannot be dislodged, but for practical purposes this can be overlooked.

Air can never be wholly driven out of the pores.

As has already been stated, the pore-volume of a soil consisting of equal particles throughout, amounts to about 38 per cent. of the space occupied by it, and 1 cubic yard of such a soil—whether we have to deal with coarse gravel or fine sand—will hold about 85 gallons of water.

1 cubic yard of soil with particles of equal size will hold about 85 gallons of water.

4. Water-retentive Power of Soil.

The water-retentive power of a soil is expressed by that quantity of water which can be retained by it; it will always be a percentage or portion of the water capacity of this soil.

The water-retentive power of soil is a percentage of its water capacity.

Soil with a large pore-volume and with a large percentage of fine pores will retain more water than soil with a small pore-volume and few fine pores. Clean gravel will retain about 12 per cent. of its water capacity, i.e. 10 gallons per cubic yard, whereas fine sand may retain as much as 84 per cent. of its water capacity, i.e. about 70 gallons per cubic yard.

Soil with a large pore-volume and a large percentage of fine pores retains more water than soil with a small pore-volume and large pores.

Clean gravel retains about 10 gal. and clean sand about 70 gal.

This will explain why a polluted subsoil containing a large amount of organic substances will retain more water than the same soil in a clean condition.

Organically polluted soil retains more water than clean soil.

The retentive power of a soil is due to the surface attraction of its particles, and when the space between them is small, or when, in other words, the pores are small, this attractive power will be all the greater.

The retentive power of a soil is due to its surface attractions.

It is further of interest to observe here, that if after the limit of the retentive power has been reached further quantities of water are poured upon the soil, the water

When, after the limit of the retentive power has been reached,

further quantities of water are poured upon the soil, a portion of the previously stored water is driven out, and its place in the pores taken up by the fresh supply.

retained in the lower layers will commence to drain away. This means that the water freshly poured upon the soil will drive out a portion of the water previously stored in the pores. It is important to bear this in mind when dealing with polluted water, as owing to this action the water penetrating into deeper layers will to some extent at least have become purified in the upper layers.

5. Capillary Movements of Water in Soil.

Capillary attraction causes an upward movement of the water.

Through capillary attraction an ascending movement of the water is caused in direct opposition to the laws of gravity, and the height to which water will thus ascend depends mainly on the smallness of the pores; large pores do not assist in this movement. As the same, however, extends over the whole pore-volume the quantity of water thus raised may exceed the water-retentive power of soil.

Capillary attraction also causes lateral and downward movements.

In addition to the upward movement brought about by capillary attraction, this power is also continually at work in a lateral and downward direction ; but for the present purposes only the upward movement will be noticed.

Time occupied by upward movement. Height reached by upward movement.

In observing the upward movement, it is interesting to notice the time occupied by it and the total height reached. As to the time occupied, it has been established that the upward movement in gravel and coarse sand is much quicker than in fine and loamy sand, but the heights attained are reversed. For whereas the height in a material consisting of coarse or large pores amounts to from 2 inches to 4 inches ; a height of about 4 feet after thirty to thirty-five days has been recorded in fine or loamy sand ; in peaty soil one observer states that the upward movement of the water may reach a height of 20 feet.

6. Temperature of Soil.

The earth's crust receives its supply of heat from three principal sources, viz.:

Three principal sources of heat.

1. From the sun through its rays;

2. From the interior of the earth through conduction; and

3. From various physical and chemical processes which take place in it and create heat.

Heat through sun's rays.

Dealing with the upper layers of the crust, it may be said that, besides the intensity of the sun's rays, the temperature also depends on a variety of properties possessed by various kinds of soil, amongst which latter may be mentioned the absorption of heat, which is much greater in dark than in light-coloured soils; the heat conductivity and the capacity for heat, which lead to higher temperatures in damp and fine-grained soils; and finally the evaporation and condensation of aqueous vapour, which tend to prevent extremes of heat and cold and which likewise produce the greatest effects in fine-grained soils.

Dark soils absorb more heat than light-coloured soils.

Capacity for heat is greater in damp and fine-grained soils.

Evaporation and condensation of aqueous vapour produce the greatest effect in fine-grained soils.

It follows from these observations that a coarse-grained, dark coloured and dry soil will show the highest and lowest temperatures, whereas a fine-grained damp soil does not get so hot but retains the heat better.

A fine-grained damp soil does not get so hot, but retains the heat better.

It ought to be pointed out in this place that a variety of circumstances may bring about very high temperatures on the surface of the ground which considerably exceed the average temperatures of the air at the same time.

The temperature of the surface of the soil may exceed that of the air.

Concerning the laws that have been deduced from careful and long continued observations of subsoil temperatures, it will not be necessary at this point to deal

Laws regulating the subsoil temperatures.

minutely with them; it must on the contrary suffice to summarise only the more important ones.

With the distance from the surface of the ground,

1. The differences of temperature become less,

2. The temperatures are retarded, and

3. The variations of short durations gradually disappear.

Subsoil temperatures 18 in. below surface.

At a depth of 18 inches below the surface the daily fluctuations are hardly observable, the temperature differences of various days become obscured, the differences between the monthly mean temperatures are less by several degrees, and the yearly fluctuation amounts only to about 10° C. At a depth of 4 feet 6 inches the latter is only 4° C., and at a depth of 9 feet it is only 1° C.

Subsoil temperatures at depths of 4 ft. 6 in. and 9 ft.

Subsoil temperatures at depths from 9 ft. to 33 ft.

Between 9 and 33 feet, according to the yearly mean of the surface, the yearly fluctuation ceases and the temperature remains the same throughout the year.

Below this point an increase of temperature is observable towards the earth's centre, which amounts to about 1° C. for every 40 feet.

Retardation of temperatures with increase in depth.

Concerning the retardation of the temperatures with an increase in depth below the surface, it is interesting to point out that this, according to Fodor, amounts to about three weeks for every yard, so that the yearly maximum at a depth of 1 yard will take place in August, at a depth of 2 yards in the beginning of September, and at a depth of 4 yards in October. This is on the assumption that the maximum temperature of the atmospheric air is reached in July.

Frost depth about 3 ft.

The depth to which frost under ordinary conditions penetrates is about 3 feet, but there are cases on record where water pipes at depths of from 4 to 5 feet have been frozen up during long continued severe frost.

7. Subsoil Air.

The pores of soil are either partly or wholly filled with air, which as a rule is saturated with aqueous vapour. This air consists very largely of carbonic acid (from 0·2 to 14 per cent., on an average from 2 to 3 per cent.) and to a small extent of oxygen, which has been used up for the formation of carbonic acid. It also contains traces of ammonia and gases of decomposition.

Subsoil air is saturated with aqueous vapour and contains large quantities of carbonic acid.

The movements of subsoil air need not be considered here, and beyond these few general observations it will not be necessary to deal with the subject.

8. Movements of Water in Soil.

Two main strata may here be distinguished in subsoil, one above the level of the subsoil water and one below this level. The latter strata do not interest us, and those above the level of the subsoil * water may again be subdivided into three zones, which in descending order are as follows :—

Strata above level of subsoil water.

The evaporation zone ;
The passage zone ; and
The capillary zone.

All these three zones must be passed by the water in its descent from the surface of the ground to the subsoil water level, and the quantity of water retained by them will depend on their state of dryness. Speaking quite generally and within wide limits, one-third of the rain-water flows off the surface, one-third evaporates, and one-third percolates into the subsoil.

One-third of the rain-water evaporates. One-third flows off the surface. One-third percolates.

* The term subsoil water is here used to denote that portion of the water in the pores of the soil, which is either at rest on or moves along the inclined plane of an impervious layer.

Evaporation zone.

The evaporation zone reaches from the surface of the soil to that point below, which marks the extent of the drying influence of the atmospheric air. In the same the quantity of water stored in the pores may at times sink below the retentive power of the soil, i.e. below that quantity which can be retained in the pores owing to the mechanical powers of adhesion, etc. When it has become very dry through evaporation and other causes the zone, especially when it extends some way down, may retain large quantities of water. In a depth of 10 inches, 1 square yard of soil, with fine pores, may retain about 10 gallons of water, and as a rainfall of ½ inch produces only 2·3 gallons per square yard, it is clear that subsoil of this nature may retain a number of successive showers. During the height of summer fine porous soil may become so dry that practically no water finds its way into deeper zones; in this state the evaporation zone can be compared to a large sponge.

Passage zone.

The next zone traversed by the water in its downward movement is the passage zone, which lies beyond the drying influence of atmospheric air. When too far removed from the level of the subsoil water, its pores will not be completely filled with water, but will only contain that amount which is due to the retentive powers of the soil. By direct measurement it has been found that on an average a cubic yard of fine porous soil will retain from 30 to 80 gallons of water, and it can easily be calculated that in a layer from 1 to 2 yards in thickness the rainfall of a whole year may be retained. The passage zone, especially if it is of considerable thickness, represents a very large storage reservoir.

Capillary zone.

The last zone before the level of the subsoil water is reached is the capillary zone, in which the pores are partially or wholly filled by the upward movement—due

to capillary attraction—from the subsoil water. The extent of this filling will depend on the size of the pores.

prings.

When the descending water has finally reached the subsoil water it either comes to a standstill altogether on the impervious layer or moves along the same, if the latter is not horizontal, until it may eventually leave the subsoil again by issuing therefrom in the form of visible or invisible springs.

Rate of downward movement governed by pores.

The rate of movement of any liquid—rain-water, sewage or other polluting liquid—is largely governed by the size of the pores. Where these are large, as for instance in coarse gravel, the descent of the water will be comparatively rapid, but when they are small it may take a very long time before the water reaches the level of the subsoil water, and in that case it will have undergone material changes as regards its chemical or bacterial composition.

With a high level of subsoil water zones become indistinguishable.

With a high level of subsoil water the zones may become indistinguishable, one zone reaching into the other, with the result that the whole of the soil becomes very wet.

When subsoil has been artificially drained the amount of water reaching the subsoil water below the general level of the drains will depend on the size of the latter and the distance between them. In such a case the downward movement of the water through undrained soil, previously described, may be further interfered with through the ventilation of the subsoil by drains, and the drying up action caused thereby.

9. THE MICRO-ORGANIC LIFE IN SOIL.

Soil probably original home of micro-organisms.

The soil is probably the original home of all micro-organisms, from which they have emigrated into other media. It contains vast numbers, and, according to some observers, 1 ccm. may hold 100,000 germs. By far the greater number is found on or near the surface, and in lower layers the numbers gradually diminish, until at last a depth is reached, which depends on local conditions, where the soil is perfectly sterile. The aerobes live near the surface and carry on their work in this region, whereas the anaerobes are at work lower down in the soil.

Distribution of micro-organisms in soil.

Cycle of micro-organic activity during the year.

The picture of the cycle of micro-organic activity in the upper layers of the soil during the various seasons of the year is probably the following. In winter, especially during that period when frost and ice bind the earth, micro-organic life is apparently at its lowest ebb, and may in some very cold climates come to a standstill altogether, when micro-organisms may be said to hold their vegetative winter sleep. With the return of life and the awakening of nature in spring—especially with the approach of higher temperatures and the formation of moisture—micro-organic activity once more makes itself felt all round. During the summer months it is exposed to some injurious influences such as the heating and drying up of the upper layers of the soil, but, still gradually increasing, micro-organisms reach the climax of their activity during the autumnal rains, to remain in this state until with the advent of the cold season their activity gradually declines again.

Micro-organic life in layers from 3 ft. to 6 ft. in depth.

In the lower layers of the soil, down to 3 feet and 6 feet, micro-organisms are more protected against the injurious influences of the atmosphere, sunlight and

drying up, but the want of oxygen, together with the greater difficulty of removing such products as carbonic acid, has an injurious influence. As the temperature in these layers is considerably more uniform, it may be inferred that the micro-organic activity is there of a more uniform kind, less influenced by sudden changes, probably also less intense, but without pronounced periods of rest.

In depths greater than 6 feet micro-organisms probably perish very quickly owing to unfavourable conditions, and if found their presence must be explained by emigration from higher layers, not by actual growth at these depths.

Micro-organisms probably quickly perish in depths greater than 6 ft.

On sewage farms the micro-organic activity is without doubt greatly modified, and proceeds all the year round at a more uniform rate than on ordinary land, as the sewage always contains the necessary warmth and moisture so beneficial for it.

10. The Absorbing Powers of Soil.

The absorbing powers of soil are due to the surface attraction of its particles or grains, and these, as has already been pointed out, will be all the greater the finer the pores are; they extend on the one hand to aqueous and other vapours and gases, and on the other to matters in solution.

Absorbing powers due to surface attraction of the particles of the soil.

The finer the pores the greater the absorption.

That the attractive force of the surface of the particles is pretty considerable will be at once apparent when it is stated that 1 cubic yard of coarse gravel may contain about 140,000 grains with a combined surface of 50 square yards, and 1 cubic yard of fine sand 40 million grains with a combined surface of 9200 square yards, which is a little under 2 acres.

1 cub. yd. of coarse gravel may contain 50 sq. yds. of surface and 1 cub. yd. of fine sand 9200 sq. yds.

Deodorising action of soil absorption of gases.

Concerning the absorption by soil of aqueous vapour and gases (apart from condensation through a fall in temperature), dry soil with fine pores acts most energetically. The almost instantaneous deodorisation of foul-smelling gases, such as are formed by decomposing fæcal matters (earth closet) or coal gas, through a thin layer of fine dry soil is well known, and is to be explained in this way.

Absorption of dissolved substances by soil.

More interesting still, and also more important, is the absorption of dissolved substances by soil. In this way is to be explained the decolorising effect and the retention of dissolved polluting substances such as are contained in sewage. In the same way soil has the power of destroying such poisons as strychnine, nicotine, coniine, etc., and the experiments of Falk and others go to show that ptomaines and toxines are likewise retained and rendered harmless by it. This absorbing power of soil is of the utmost importance in agriculture, and without it soil could not possess purifying powers for polluting liquids. It is quite true that in this process of purification other factors play an important part, but they could not come into play if this absorption did not exist.

The absorbing powers of soil are in some way dependent on the presence of micro-organisms and air, and in the absence of these they will soon come to a standstill.

IV. SELF-PURIFYING POWERS OF SOIL. NATURAL SELF-PURIFICATION OF SEWAGE.

After these preliminary remarks it becomes necessary now to examine into the self-purifying powers of soil with special reference to sewage farms. Generally

speaking, the term "self-purifying powers of soil" comprises all those processes which go on on the surface and in the pores of the soil of sewage farms, and by which polluting liquids such as sewage become purified as these take place under natural conditions and in a natural medium, the process of land treatment of sewage is called—see previous observations—"the natural self-purification of sewage."

Self-purifying powers of soil.

It should be stated at the outset that the self-purifying powers of soil will depend largely on the soil itself and the local conditions under which they come into play, so that observations made in one locality will not be immediately applicable to others without making full allowance for the differences; this will be clear from the preliminary remarks as to the character and properties of soils made in the previous pages. As will be pointed out more in detail later on, a subsoil that combines great permeability for air with high retaining and absorbing powers, is best suited for sewage farms.

Self-purifying powers vary with local conditions

Soil best suited for sewage farms.

Let us now consider what becomes of water, sewage or any other polluting liquid containing organic substances after it has been poured out upon the surface of the ground, and for this purpose we will assume a subsoil of a suitable character and in fair condition for work with proper under-drainage.

The liquid thus poured out upon the surface will sooner or later disappear in the soil, and will at first be retained in the pores of the zone of evaporation, which may be said to extend to the level of the under-drains. This retention is due to the retentive powers of soil.

Retention of liquid by pores of soil.

Portion of the suspended matters will be retained on the surface and the rest will be strained out in a mechanical manner in the pores, the soil acting as a sieve more or less fine according to its character. If

Suspended matters retained on the surface, soil acts like a sieve.

Coating of surface of the land.

the suspended matters are present in very large quantities it may happen that they will gradually form a coat on the surface of the land and choke the pores to the exclusion of air, and as this is a thing to be avoided in sewage farming it is in most cases advisable to remove them out of the liquid before it is poured upon the land.

Removal of suspended matters generally an advantage.

The more finely divided the suspended matters are, the lighter the work of the land.

Even where such a removal has taken place there will still be left a certain portion of the suspended matters, and if these are in a finely divided state, such as is probably the result of their passage through fine strainers or pump valves, the work of the land will be considerably lightened.

Micro-organisms screened out in a mechanical way.

The micro-organisms contained in the liquid will be to a large extent screened out in a mechanical way with the suspended matters and deposited on the surface and in the upper layers of the soil.

Retention of matters in solution after removal out of the liquid is due to physical and chemical agencies.

The matters in solution will partly, after removal out of the liquid, be retained by the absorbing powers of the soil in the pores, a process that is due to physical and chemical agencies.

It is well known that land which is being treated with sewage for the first time does not purify sewage so well as land that has been under systematic treatment for some time, and this is probably due to the absorbing powers, which gradually ripen until they have reached their maximum of efficiency. This process of gradual improvement seems to be due to the formation of a slimy coating round each particle of soil, which growth does not only assist mechanical filtration, but also possesses high powers of absorbing oxygen.

Absorbing powers gradually ripen.

Depths to which polluting substances may penetrate into soil.

The depth to which polluting substances may penetrate into soil will probably differ in each case, but the following factors may be said to influence it, viz. the

velocity of the downward flow, the nature and degree of the polluting liquid, and the character of the soil. Where, therefore, the powers of the soil are over-taxed the polluting substances may reach the level of the under-drains and pass out through them, in which case the effluent will be but little better than the raw liquid. It must be the aim of careful management to avoid this.

Process of decomposition of organic matters stored in soil during periods of rest.

The polluting substances of an organic nature thus stored in the pores undergo here—and that probably chiefly during periods of rest—a process of decomposition or disintegration, which goes on until the whole of the organic matter has been converted into stable mineral forms.

Explanation of the term "self-purifying power of soil."

This process of retention, absorption and decomposition of organic impurities is called "the self-purifying power of soil."

After conversion substances are removed out of the soil by the plants, by the subsoil air and subsoil water.

The substances thus converted do not remain in the pores, but they are removed either by the plants, for which they act as food, or by the currents of subsoil air, or by the subsoil water, and as the removal of fertilising substances by the subsoil water indicates a waste it must be the aim of a careful management to utilise them as much as ever possible for the benefit of the plants.

Process of digestion. "Sewage sick."

The whole of these intricate and very complicated changes may be likened to the process of digestion in animals, and when these digestive powers are overtaxed signs of sickness may be noticed as the inevitable result, which increase until, in sewage phraseology, the land becomes "sewage sick." In this condition it remains until the flow of the polluting liquid is stopped, when after a period of rest—recreative period—the digestive powers gradually return and begin to do their work afresh.

When the soil of a sewage farm has got into this

state, owing to having received heavy doses of sewage, the application of lime has proved very beneficial by accelerating the process of nitrification, and in this respect interesting experiments have been made on the Berlin sewage farms. The action of lime is said to be a twofold one.

Action of lime.

1. It quickly attacks and splits up the organic matters and accelerates afterwards their decomposition and their utilisation by plants; and

2. It neutralises the excess of acid in the soil, and causes the latter to part with its carbonic acid.

Decomposition proceeds quickest at or near the surface.

The process of decomposition proceeds as a rule at a much quicker rate on the surface and in the upper layers of the soil, where, as already mentioned, the number of micro-organisms is greatest.

When carefully worked there is no time limit to the purifying powers of the soil.

It has been maintained that the soil of sewage farms will after a while silt up and cease to purify sewage, but the results obtained with carefully managed farms clearly disprove this, and under these conditions there appears to be no limit as to time to the purifying power of soil.

Depth of soil necessary for purification.

Concerning the depth of soil—evaporation zone—that is necessary for the successful retention, absorption and decomposition of sewage, no generally applicable rule can be laid down, as this will depend on a variety of factors, amongst which may be mentioned: the character and thickness of the top soil (humus), the nature and cultivation of the top soil; the character of the subsoil—its permeability for air and its retaining and absorbing powers; the surface slopes of the land and the level of the subsoil water.

Greater depths than 4 ft. will be rarely necessary.

On some farms a depth of 3 feet on an average has proved sufficient, and on others the drains have been laid at depths ranging between 3 and 6 feet, but very

special reasons ought to be shown for all depths over 4 feet.

Whilst practically no soil is entirely useless for sewage farming, with the exception perhaps of peat, owing to the quantity of moisture it contains, a soil that combines great permeability for air with high retaining and absorbing powers—such as a loamy sand with fairly large grains—is probably the best.

Soil best suited for sewage farms.

It has been maintained that clay, owing to its impervious character, is totally unsuitable for sewage farming, but the experience of such farms as South Norwood, Wimbledon, Warwick and Leicester disproves this. It is true, however, that as the purifying powers of the soil are restricted in a vertical sense to the upper layers, it may become necessary in places to extend the area of the farm beyond what would be necessary with a more pervious soil.

Clay soil not unsuitable for sewage farms, but it necessitates a greater area of land.

It may not be without interest to draw attention here to some of the changes that have taken place on the Leicester sewage farm since the land has received regular dressings of sewage. When I was engaged in laying it out in 1888 my powers of locomotion over the land were greatly impeded during wet seasons by the inordinate amount of clay that adhered to the boots; but when engaged again for some considerable time on the land during the winter 1900 to 1901 this unpleasant peculiarity had completely disappeared even on land that had recently been sewaged. Through the action of the sewage the very dense clay had been disintegrated and become so pliable that, when trod upon, it crumbled to pieces. The colour of the soil had been changed from a yellowish-brown to a greyish-black, and altogether the land had been greatly improved by the application of the sewage.

Changes observed in the heavy clay land at Leicester since sewage treatment was commenced.

Movement of liquid through the passage and capillary zones to the impervious layer.

If more sewage is poured upon the land than the effluent drains can deal with—and here it may be well to bear in mind that on sewage farms in our climate on a broad average throughout the year about one-third of the total quantity is lost by evaporation—the excess will pass down between the drains from the evaporation to the passage zone, and if the flow of the sewage is not discontinued the downward movement in the passage zone may be continued until, after having traversed the capillary zone, the level of the subsoil water is reached.

Length of downward movement of water may be very great.

What length of time may elapse before this level is reached will entirely depend on local circumstances, but it will be clear from the preliminary remarks that the completion of this downward movement may in places and under certain conditions take a very long time.

Displacement of sewage held by the pores of the land by the fresh discharge of sewage upon the surface of the land.

In connection with this it is of importance to point out that not the fresh sewage which is poured on the surface of the land will at once pass into the lower layers, but a portion of the old sewage, which up to then was stored in the pores and is now displaced by the fresh discharge, so that the fresh raw sewage is retained and only purified sewage allowed to escape into deeper layers, which means that in its downward movement all sewage undergoes purification. Were this not the case the raw sewage might reach the effluent drains.

It appears time now to examine somewhat more closely the processes of decomposition and the products elaborated therein.

Factors that influence the process of decomposition.

Concerning the factors which have a favourable influence upon this process, some of them, such as permeability for air, high retentive and absorbing powers, have already been mentioned, and to these can be added moisture and warmth, the latter of which are always present in sewage.

Advantages of a systematic under-drainage.

One word here concerning the systematic under-drainage of the subsoil. Its chief function is, of course, the carrying away of the effluent water and by doing so to prevent the formation of a swamp, but after the land has done its work, and during so-called periods of rest, the under-drains act as ventilators of the subsoil and thus make it artificially more permeable for air, with the result that a drying-up action is set up and oxygen supplied for micro-organic life. For the purpose of improving the ventilation of the soil it may become advisable in places to connect the upper ends of the drains with a short upcast shaft. The mouths of the drains should always discharge above water so as to allow of a free circulation of air.

Micro-organisms that carry on the work of splitting up and converting organic compounds.

The work of splitting up and converting the organic compounds is primarily carried out by micro-organisms such as yeast fungi, mould fungi, algæ, protozoa and even by higher forms of life such as earthworms and insects.

To what extent in addition to these other agencies take part in this bio-chemical process is not yet fully elucidated.

Decomposition and putrefaction most complicated processes.

Fischer in his interesting book, 'The Structure and Functions of Bacteria,' observes (page 99): "The decomposition of dead animal bodies, of vegetable tissues, or of substances like stable manure, is far from being a simple putrefactive process. Side by side with the disintegration of nitrogenous bodies there are going on a number of fermentative changes by which non-nitrogenous compounds are being broken up, besides nitrification and other bio-chemical processes. For this reason it is always difficult and often impossible to determine the respective parts played by the different species of bacteria. . . .

"The phenomena of putrefaction are so complicated that we do not know all of the compounds that arise during the process. . . . Very careful chemical investigations on pure cultures will be necessary before the chaos of phenomena presented by putrefactive bacteria can be arranged in something like order.

In the decomposition of proteids five or rather six stages may be distinguished.

"Proteids are split up by putrefaction into a large number of simpler compounds both nitrogenous and non-nitrogenous. The substances thus produced are precisely similar to those resulting from the artificial decomposition of proteids by fusion with caustic potash or boiling with hydrochloric acid or barium hydrate. Five groups may be distinguished:

Albumoses and peptones.

"1. Albumoses and peptones: soluble diffusible bodies closely resembling albumen. They are produced by the action on albumen of bacterial enzymes, similar to the enzymes (pepsin and pancreatin) which give rise to peptones in the digestive tract of man.

Aromatic compounds.

"2. Aromatic compounds: among others indol and skatol, which give the characteristic odour to human excrement; also some non-nitrogenous substances such as phenol, phenylacetic acid, and phenylpropionic acid.

Amido compounds.

"3. Amido compounds, all nitrogenous: leucin, tyrosin, aspartic acid, glycocol.

Fatty and aromatic acids.

"4. Fatty and aromatic acids, all non-nitrogenous and therefore having no part in the circulation of nitrogen: acetic, butyric, succinic and valerianic acids.

Inorganic end-products of putrefaction.

"5. Inorganic end-products of putrefaction: free nitrogen, ammonia, free hydrogen, methane, carbonic acid, methylmercaptan, sulphuretted hydrogen. It is probable also, but not certain, that phosphuretted hydrogen is formed and is oxidised at once by the free oxygen of the atmosphere.

"Most of these substances are formed also by the

chemical decomposition of proteids, but there is a sixth group which may be termed specific putrefactive products. These are the so-called ptomaines or putrefactive alkaloids." **Ptomaines.**

Some of these bodies are either not poisonous or only poisonous in large doses, whilst others, derived from putrid foods of various kinds (sausages, cheese), are highly toxic (ptomatropine, tyrotoxine).

Definition of some terms. Concerning the work done by micro-organisms, it may not be out of place here to define the meaning of certain terms, and to direct attention at the same time to the modifications in the results brought about by the presence or absence of air during the various stages of the process.

The terms mineralisation, disintegration, oxidation, hydrolysis, bacteriolysis, nitrification, decomposition, eremacausis, putrefaction, fermentation, etc., have by many been used somewhat promiscuously, and this has led to a good deal of confusion, bewilderment and misconception. The cause of this has been undoubtedly our small amount of knowledge concerning this process and the changes brought about therein, but this would appear to be no reason why complication should be made worse. For the purposes of these remarks the undermentioned terms shall have the following meaning.

Mineralisation. The term "mineralisation" is used for describing the whole process of the disintegration and conversion of organic into mineral matter, and no distinction shall be made between organic matter containing nitrogenous and organic matter containing carbonaceous substances.

Aerobic fermentation or decomposition. When this process of mineralisation is carried on in the presence of sufficient quantities of air it is called "aerobic fermentation," or "decomposition," which is generally characterised by the absence of strong smells.

The process may then be called one of complete oxidation.

Anaerobic fermentation or putrefaction.

Where, however, the mineralisation proceeds in the absence of air the process is called "anaerobic fermentation," or "putrefaction," and it is then that very pronounced foul smells are emitted. The process may then be called one of incomplete oxidation.

Obligatory aerobes and anaerobes.

That class of micro-organisms which can only live in the presence of oxygen is called "obligatory aerobes," and that which can only exist in the absence of this gas "obligatory anaerobes." Between these two is the group of "facultative anaerobes," which, while growing best with a plentiful supply of oxygen, are nevertheless able to exist with a very small amount, and even with none at all, although in this case their vitality is often much impaired.

Facultative anaerobes.

Organic matters are first split up and then converted into mineral substances.

In the process of mineralisation two stages may be distinguished, viz. the first or disintegration stage, and the second or oxidation stage, i.e. the organic substances are first split up and afterwards converted into inorganic ones ; and frequently these processes are taking place side by side and not after each other.

The splitting up of organic substances is frequently carried out in the presence of air.

It has been maintained—probably with a view to justifying the necessity of a septic tank—that the preliminary process of splitting up is best carried out in the absence of oxygen, but sufficient proof does not appear to have been advanced in support of this statement, and in some cases at any rate it is evidently carried out quite satisfactorily in the presence of air.

Concerning the presence or absence of oxygen, Fischer observes as follows :—

"The effects of the presence of oxygen are somewhat better understood. If air have free access, putrefaction (decomposition) may go on without any odour at

all, the evil-smelling gases (NH_3 and SH_2, for example) being oxidised at once to form nitrates and sulphates. Aerobic bacteria, too, such as the nitre and sulphur bacteria, bring about this mineralisation of organic nitrogen. Moreover, when air is circulating freely, there is no accumulation of intermediate products such as skatol or indol. It occurs on the surface of manure heaps, on the outer surfaces of carcases, and in well ventilated soil.

"In anaerobic decomposition (putrefaction proper), as in anaerobic fermentation, the organic molecules are at first only partly disintegrated, intermediate products such as leucine, tyrosine, skatol and indol being formed. In the absence of air these accumulate, and hence it is that putrefaction going on in the mud of ponds and ditches, or inside carcases, is accompanied by such evil odours.

"Although the details of the process vary considerably, according to the presence or absence of air, the ultimate products of decomposition and putrefaction are in both cases the same: namely, free nitrogen, free hydrogen, ammonia, methane, carbonic acid and sulphuretted hydrogen. These are also the end-results of the disintegration of the human body.

"After the organic nitrogen of decomposing substances has been converted into ammonia, and to a small extent into free nitrogen, the latter can at once be utilised by the root-nodule organisms and other bacteria in the soil, but the ammonia must undergo two further changes and combine with a base to form a nitric salt before it is available for plant life. These two changes are brought about by bacteria, which convert the ammonia first into nitrous and then into nitric acid; this process has been called 'nitrification.'"

It will be clear from the foregoing remarks that the process of mineralisation is a very complicated one, which under favourable conditions, for instance in the pores of an open soil, may come to an end fairly quickly, but which under very unfavourable conditions—such as the interior of large heaps of refuse—may last many years.

Chemical purification on sewage farms.

Concerning the chemical purification effected on sewage farms, i.e. the purification of the sewage as revealed by chemical analysis, it has been put on record over and over again, and is now fully and universally understood, that suitable land well managed is capable of changing even the foulest sewage to a perfectly clear water devoid of smell and danger, so that this point need not be laboured here. For instance, on the Berlin sewage farms the degree of purification attained has averaged for a period of 20 years 97 per cent., and on the farm at Gennevilliers—one of the Paris sewage farms—the effluent is so sparkling, bright and clear that the inhabitants drink it in preference to other available water.

Micro-organic purity of effluent from sewage farms.

But in reference to the purity of the effluent as to the products of micro-organic activity and pathogenic micro-organisms, it will be necessary to make a few observations with a view to remove misconceptions that have from time to time been put forward.

Ptomaines have not been found in effluents from well managed sewage farms.

The question whether the specific products of putrefaction, i.e. the putrefactive alkaloids "ptomaines and toxines," are capable of doing further mischief by escaping with the effluent into the stream, may be answered as follows. These substances are fortunately very unstable, and the experiments conducted by Falk and others seem further to indicate that soil is capable of retaining them and of rendering them harmless. At

any rate there is no well authenticated case on record of these bodies having wrought mischief on sewage farms. (See here also the remarks made on pages 51 and 52 under the heading "The Absorbing Powers of Soil.")

Pathogenic germs on sewage farms.

It has further been maintained that the presence of pathogenic organisms on sewage farms might in two ways lead to mischief, viz. either by transmission through air or by transmission through water. The pathogenic organisms after spreading over the land might rise into the air through the movements of the atmosphere and then be carried about by it, or they might escape through the land and be conveyed with the effluent into the stream or river that takes the latter.

Pasteur's fears as to mischief likely to be brought about by pathogenic micro-organisms on sewage farms not borne out by facts.

In connection with this point it may not be without interest to mention here that even the late M. Pasteur at one time of his career considered the wholesale spreading of disease germs on sewage farms might prove highly injurious to the public health of the neighbourhood. As he himself admitted, he based his fears on purely theoretical considerations and opposed, for this reason, the extension of the sewage farms in the neighbourhood of Paris. But when, later on, he was made acquainted with the results observed on the Berlin farms, he tacitly modified his views and ceased to oppose the extension of the Paris farms.

No well-authenticated case is on record where a sewage farm has acted as the focus of a local outbreak of typhoid fever.

Indeed, search as I might, I have not been able to discover one single instance where a sewage farm has acted as the focus of a local outbreak. On the contrary, during one or two small epidemics of typhoid fever in Berlin, no case of this complaint has been observed on the sewage farms of that city.

Experience on the Berlin farms.

Concerning the escape of pathogenic micro-organisms into streams and rivers, no case is on record where such

a thing as actually occurred: indeed, the very painstaking investigations on the Berlin farms have led to negative results.

Observations made at the Freiburg sewage farm.

Another sewage farm, that of Freiburg in Baden, has likewise been made the subject of careful and long-continued investigation by Dr. Korn, who, for the twelve months ending August 1897, made no less than 165 elaborate chemical and bacteriological examinations. Summing up his observations on the presence of bacteria in the effluents from subsoil drains, he remarks:

"Apart from the few exceptional cases of high numbers, generally speaking my experiments show that the number of germs in the subsoil drain effluents is relatively small, and even omitting these experiments, in which a dilution with subsoil water must have taken place, the number of micro-organisms is still so small that the effects of filtration through soil are clearly perceptible. In addition to this—and this is of considerable importance in forming a judgment—it must be borne in mind that the bacteria in sewage are principally derived from the intestines, whereas in the subsoil drain effluents the inhabitants of the intestines are either not present at all or only in very small numbers compared with the number of soil and water bacteria, which are always present. Out of 165 examinations I only succeeded in 18 cases in proving the presence of bacterium coli."

Bacterium coli no longer a true criterion of sewage pollution.

It may be convenient to point out in this place that bacterium coli can no longer be looked upon as a typical inhabitant of the human intestines after the very elaborate investigations carried out by Dr. Weissenfels, who arrived at the following conclusions:

Dr. Weissenfels' conclusions.

1. The so-called bacterium coli can be cultivated from almost every kind of water, and its presence can be

demonstrated in nearly every case, provided a sufficient volume of water is utilised.

2. It is not possible by the result of the experiments upon animals to decide whether the bacterium coli was cultivated from a pure or infected water, and the discovery of a virulent bacterium coli in any sample of water cannot, therefore, be regarded as a criterion that such water has been polluted with fæcal bacteria.

After these remarks, it would seem quite possible that the bacterium coli discovered in eighteen cases by Dr. Korn in the Freiburg effluents was not derived from sewage at all but from the ordinary subsoil water of the land.

The possibility of further mischief by pathogenic micro-organisms on sewage farms is exceedingly remote, if it exists at all.

Bearing these observations in mind, it is quite clear, therefore, that neither theoretical investigations, as available up to now, nor practical results, support the theory that pathogenic micro-organisms may do mischief on sewage farms, and one is forced to conclude that this possibility—if it exists at all—after systematic treatment on land is an exceedingly remote one.

Sewage farms reduce the quantity of final effluent.

Before concluding these remarks on the natural purification of sewage it is necessary to draw attention to another considerable advantage which it possesses over artificial sewage treatments, and that is the reduction in quantity of the effluent, which at times is very considerable, whereas in the artificial methods such a reduction is comparatively small.

Loss of liquid by evaporation and by plant life.

Spread over a large area of land, well cropped, evaporation is very active—especially during the summer months, when the flow of water in the brook that takes the effluent is as a rule at its lowest; and, in addition to this, the growing plants further abstract a considerable amount of the liquid that finds its way into the soil, so that the quantity of the effluent may not be more than from 30

to 50 per cent. of the total quantity that was poured over the land. In the artificial treatment the evaporation is considerably smaller, and as plants are altogether absent the quantity of the effluent is probably about 90 per cent. and more of the total quantity of the raw sewage. This is a point of very considerable importance so far as the influence of the effluent upon the water in the stream that takes the same is concerned.

Although the subject of natural purification is by no means exhausted, it is now time to direct attention to artificial methods.

V. ARTIFICIAL SELF-PURIFICATION OF SEWAGE.

1. General Observations.

Enumeration of more important experiments.

A great many experiments have been made during the last ten years with artificial processes for the self-purification of sewage, and amongst the more important the following may be mentioned:

London experiments.	Sheffield experiments.
Sutton "	Leicester "
Exeter "	York "
Manchester "	Hamburg "
Leeds "	

Experiments have not been conducted on uniform lines.

A casual observer might, therefore, consider himself justified in thinking that all these experiments had added a great deal to our knowledge of the intricate changes taking place in these processes, but such a conclusion would not be justified in reality. For beyond settling questions of local importance by chemical analysis, the experiments, owing to a variety of causes, have not

materially enhanced the stores of our information, indeed not unfrequently the results obtained are apparently contradictory and bewildering.

An experiment must be looked upon as a question addressed to nature, and the answer will depend on the way the question has been put. If this way differs in every case it must be clear that the answer, too, will differ in every case, and it is this absence of uniformity which greatly reduces the general value of these experiments.

These remarks must not be misunderstood to convey the impression as if the experiments had not been conducted with care and skill! Far from it! Some of them have been made with the greatest skill and care and with the very evident desire to arrive at correct conclusions, and it is only when they are placed side by side with other experiments, with a view to deducing from them general conclusions concerning the processes at work, that great difficulties are experienced. The result of each experiment is governed by a large number of factors, which by slightly different manipulations may attain in this ever-fluctuating process different weights, so that the results may be contradictory, and it is only by arranging these factors on a common basis, as it were, and by addressing the questions to nature in the same systematic and uniform way, that good general results may be expected.

It is well known, for instance, that in some cases septic tanks have not given good results, whilst in others they have worked very well; again, continuous filtration has failed in some experiments, whilst in others, notably in the York experiments, it has given good results.

If, therefore, in future the mistake of the past is to be avoided, it will be necessary to settle on a common line of action in all experiments.

Attempt to evolve general theory.

In spite of all the difficulties which beset such a task, an attempt will be made in the following observations to evolve some general theory concerning the processes at work in the artificial self-purification of sewage. Such a theory, it is quite clear, cannot be complete in the present state of our knowledge, and it is sincerely hoped that the many and serious gaps will be filled up by later investigations.

For convenience of reference the different forms of the process, such as are now employed, shall be dealt with separately, commencing with contact or oxidation beds.

2. Artificial Self-Purification of Sewage in Intermittent Contact Beds.

At the outset it may not be out of place to make a few remarks concerning the various names given to this form of application. The term "intermittent contact bed" is here used to distinguish this kind of bed from the "continuous contact bed," frequently called "continuous filtration."

Names of process misleading.

(*a*) *Name of Process.*—This process has frequently been called "biological process," "bacteriological process," "contact bed system" or "oxidation bed system," but all these terms do not appear to define it sufficiently, as they do not cover the whole, but only phases or stages in the same; hence, they do not seem appropriate.

Biological process.

The name "biological process" is decidedly misleading, for besides biological agencies there are also at work physical (mechanical) and chemical ones.

Bacteriological process.

The term "bacteriological or bacterial process" is likewise erroneous, for besides bacteria a number of other micro-organisms participate in it—such as yeast

fungi, mould fungi, algæ, protozoa, and even higher forms of life, such as earthworms and insects.

The expressions "contact bed system" or "oxidation bed system" are in so far inappropriate as they describe only portions of the process but not the whole. The term "contact bed" describes the first stage, and the term "oxidation bed" portion of the second stage only.

Contact bed system.

Oxidation bed system.

The term which seems most suitable of all is "artificial self-purification in contact beds," as it includes every phase of this lengthy process applied in an artificial form ; the term "natural self-purification" being applied to land treatment of sewage, as it is the only method in which the self-purifying powers are employed under natural conditions.

Term most suitable.

(*b*) *Explanation of Process.*—The cycle of operations commences with the filling of the bed, and during the same the sewage comes gradually in contact with the filling material. When the bed is full, the inflow is stopped and the sewage allowed to remain in contact with the material for some time. The bed is then emptied, and a period of rest is given it before the filling is commenced again.

Working operations.

It has been held, that while the sewage is in the contact bed it undergoes a very rapid process of decomposition by bacteria, but it must be evident, that as the sewage—including filling—remains only for about two hours in the bed, the micro-organisms would have to work at an express rate. This fact alone is apt to make this theory very doubtful, but apart from it, it has been proved by experiments that the by far greater amount of purification—whilst the sewage is in the beds—is due to the absorbing powers of the filling material, which are derived from the surface attraction of its component particles.

Purification of sewage in full bed due to absorbing powers of filling material and only to a small extent due to activity of micro-organisms.

Retention of suspended matters by bed.

Absorbing powers of filling material.

The filling material retains in its upper layers the suspended matters, which it strains out of the sewage in a purely mechanical manner, much after the fashion of a screen, and when the bed is filled its absorbing powers come into play, which cause the removal of the dissolved matters out of the liquid and their retention on the surface of the particles. This latter process is probably a chemico-physical one assisted by the micro-organic life in the sewage.

Decomposition of organic substances by micro-organisms when bed is empty.

It is only after the bed has been emptied that the real activity of the vast number of micro-organisms commences, which is directed towards converting the organic substances into mineral ones. This process of splitting up, decomposing, disintegrating and mineralising organic waste products is an exceedingly complex one, which ever fluctuates according to the prevailing conditions, and which does not come to an end until finally stable mineral forms are reached. In the presence of a plentiful supply of oxygen, the process proceeds as a rule at a more rapid rate, and the intermediate forms produced are less complex than in the comparative or total absence of this gas; hence the progress of the process is largely determined by it. The amount of oxygen necessary for bacterial activity is partly abstracted, and with extraordinary energy, from the atmospheric air in the pores of the filling material, and a portion of the substances formed, such as carbonic acid and nitrogen—in gas form—escape into the atmosphere, whilst the remaining portions are washed out of the bed with other products, such as nitric acid, by the effluent.

Further remarks upon this process of mineralisation have been made in connection with the subject of natural self-purification of sewage, and these may be referred to here.

The effect of the bed upon the bacterial flora of sewage is, as was to be expected, but very slight, and it is on record now that, as far as the micro-organic life is concerned, the effluent is to all intents and purposes raw sewage.

Effluent from bed practically raw sewage as far as its bacterial contents are concerned.

Some of the substances contained in raw sewage remain in the bed, no matter how carefully the sewage has been previously strained, and these, in combination with the slimy surface coating of the component particles, the accumulation of mineralised substances in the pores, the consolidation of the bed, the disintegration of the filling material, and the liquid retained, lead gradually but surely to the silting or sludging up of the bed.

Silting up of bed.

(*c*) *Water Capacity of Bed and Silting up.*—The theoretical water capacity of the bed, previous to commencing operations, is the aggregate of the cubical space occupied by the pores or small passages between the particles forming the filling material, and the pores of the filling material itself; but in practice a certain amount of this space is occupied by air, which it is impossible to dislodge altogether in filling. The aggregate of the cubical space of the pores may be called the pore-volume.

Theoretical original water capacity of bed.

It is difficult to lay down general rules as to what the original water capacity of a bed should be expressed in per cent. of the space occupied by the filling material, but speaking within fairly wide limits the following is somewhat near the truth.

When the particles forming the filling material are fairly spherical and of equal size, the original water capacity of a bed amounts to about 38 per cent. of the space occupied by the filling material; but as in practice it is difficult to obtain spherical particles of uniform size, the original water capacity is found to range from 35 to 45 per cent. of this space.

Original water capacity with spherical particles of uniform size.

Original water capacity with particles of different sizes. When, however, the particles are of materially different sizes, and when the smaller ones fill up the spaces between the larger ones, the original water capacity may sink down to as low as from 5 to 10 per cent. of the space occupied by the filling material.

Size of particles of filling material does, under certain conditions, not affect original water capacity of bed. It has been further demonstrated that the water capacity of a bed is not affected by the size of the particles, provided the latter are spherical and of uniform size. In other words, the water capacity of two beds filled with material of different sizes is the same, provided the particles are spherical and of uniform size throughout each bed.

Silting up of bed during regular work. This original water capacity is, however, not maintained in regular work, as has been pointed out already. Basing the observations on regular work only, the original capacity decreases at first, after a new bed has been started or after an old reconstructed bed has been taken in hand, rapidly for some time and afterwards more slowly. Graphically expressed, this decrease is not represented by a straight line but approaches more nearly a parabolic curve. This initial rapid decrease is chiefly due to the consolidation of the bed.

Rapid initial decrease of capacity.

Consolidation of bed.

In connection with the movements in the bed tending towards its consolidation, it is also clear that the continual filling and emptying operations cause the smaller particles to be washed out of their original position and to be placed in the larger passages between the filling material, and if this process is assisted by the gradual disintegration of the particles composing the filling material, it is clear that the pores must become smaller and smaller in time, i.e. choked.

Disintegration of filling material.

From these observations it follows that the filling material should be a hard substance, which will only to a limited extent be subject to this crumbling away process.

But besides these there are, as has already been pointed out, other silting up agencies at work.

Water-retentive power of filling material.

Of the total quantity of sewage which has entered the bed a small portion will always remain in it owing to the water retaining power of the material. This power has sometimes been called "minimum water capacity," but as this name is liable to be misunderstood, it is better to adopt here the term "water-retentive power" of material.

The quantity of the sewage retained by the bed varies with the material and pore-volume, and is due to adhesion and capillary attraction. The greater the pore-volume, and the greater the percentage of fine pores, the greater is the quantity thus retained. Clean gravel retains about 12 per cent. and fine sand about 84 per cent. of its water capacity—i.e. expressed per cubic yard of filling material, one cubic yard of clean gravel will retain about 10 gallons and one cubic yard of fine sand about 70 gallons of water.

Through draining a bed for several hours through evaporation and other atmospheric influence, a portion of the sewage retained is lost, but the quantity so lost will vary continually with the circumstances under which the bed is worked.

The water-retentive power of the filling material does not decrease with the working of the bed, but increases, which in a large measure is probably due to the slimy coat which forms round the surface of the component particles, and to which reference is made in the following paragraph.

Slimy surface coating of component particles.

A further silting-up agency is the slimy surface coating of the particles of the filling material. This accumulation is well known to all who have had to do with intermittent contact beds, and has been described as

spongy bacterial growth. The Manchester report for the year ending March 27, 1901, contains on page 62 the following passage: "This (spongy bacterial growth) is at once the cause of increased efficiency in the bed and loss of capacity. On examining the material of a contact bed in active condition, every piece is seen to be coated over with a slimy growth. If this is removed it soon dries to a stiff jelly, which can be cut with a knife. Under the microscope masses of bacteria and zoogloea will be found to be present."

Accumulations of decomposed substances in the pores.

In addition to this slimy surface-coating of the particles, there are also found in the pores, especially in the upper layers of the filling material—and in fine beds more so than in a coarse bed—accumulations which are "akin to humus or garden soil." They contain to a limited extent only putrescible substances, and appear to be the remains of organic matter decomposed by the activity of micro-organisms.

Periods of rest will not permanently restore portion of the original water capacity of the bed.

It was formerly maintained with considerable persistency that periods of rest would permanently restore to a systematically worked bed a portion of its lost water capacity, but such a contention has been proved to be wrong. It is quite true that immediately after periods of rest an increase of the water capacity is very noticeable, which is probably due to drying up processes within the bed during the rest, but such an increase is not permanent and is lost again more or less quickly; it is therefore only temporary and not permanent.

Where, however, a bed has not been systematically worked, i.e. where it has been worked at a greater rate than is suitable, and where in consequence of this a large quantity of undecomposed substances is stored in it, a period of rest may permanently restore a portion of the lost capacity; but this is due to the mineralisation

of these undecomposed organic substances during the rest.

It follows from these remarks, as has been stated above, that when the organic substances are regularly decomposed during systematic work a period of rest cannot materially affect the water capacity, and that where a considerable permanent restoration of the water capacity takes place the bed has not been properly worked.

Decrease of capacity is accompanied to some extent by increase of efficiency and *vice versa.*

It would, however, be incorrect to assume that the silting up of the bed affects its efficiency besides reducing the capacity. On the contrary! To some extent decrease of capacity is accompanied by increase of efficiency and *vice versa!*

Higher capacity of beds in summer than in winter.

At this point it ought to be stated that in the Manchester experiments (see page 61 of the report for the year ending 27th March, 1901) a higher average capacity is maintained during the summer than during the winter, which is no doubt due to the greater activity of the micro-organisms during the warm weather of the year.

Raking of beds not advantageous.

The raking of the surface does not materially affect the capacity of the bed, and it is better to scrape off the matters retained on the surface than to rake them into the body of the bed.

Renovation of filling material either partially or wholly.

It will be clear from these observations that, no matter how carefully the bed has been worked, sooner or later a time will come when the decrease of capacity becomes so pronounced as to render it impossible any longer to treat the daily flow of sewage with the available plant; and when this point has been reached a renovation, either partially or wholly, of the filling material becomes an inevitable necessity.

Minimum capacity of beds to be provided for.

To provide for this at the outset, and thus avoid the

difficulties of reduced capacity, it seems advisable to lay down, when designing the works, a minimum capacity, which will just allow the daily volume of sewage to be treated by the plant, and which when reached will necessitate the cleansing of the bed.

The idea, formerly frequently expressed, that the filling material when rationally worked need not be renewed or renovated, can no longer be maintained and is outside the reach of practical possibilities.

Under-drainage of intermittent contact beds.

At this place a word or two about the under drainage of intermittent contact beds may not be out of place. It is of the greatest importance that all drains should work well, and that the entrance of the sewage into them should not lead to disturbance in the filling material, especially should the tearing of portions of the filling material into the drain pipes be avoided.

By carefully arranging the position, number, size and fall of the master drains and branch drains, it is possible to reduce the resistance so as to allow of a fairly even flow of sewage through all the drains, and to prevent a great rush of water through the drains near the outlet end.

The presence of lime is of no consequence.

In passing it may not be out of place to point out that the view, formerly expressed, that an admixture of lime in some form would prove advantageous to the purification of sewage, is not supported by the experience gained.

Absorbing effect increases with the time of contact.

(*d*) *Absorbing Powers of Filling Material.*—The absorbing effect of any filling material seems to increase with the time of contact.

Absorbing powers increase until bed has become ripe.

It ought further to be pointed out that the absorbing powers of the filling material gradually increase until the bed has become ripe. This fact was formerly stated to be due to the development of the proper micro-organisms

within the bed, but it would seem to be chiefly due to the slimy surface coating of the particles of the filling material, or spongy bacterial growth, as it has frequently been called, which does not only assist mechanical filtration but also possesses high powers of absorbing oxygen.

Absorbing powers soon cease in the absence of micro-organisms and air.

But it cannot be open to doubt that the absorbing powers of the filling material are dependent in some way or other on the presence of micro-organisms, for Dunbar has shown that in the absence of micro-organisms and without periods of aeration these powers soon cease.

Oxygen is absorbed from air in the pores with great energy.

(*e*) *Consumption of Oxygen by the Filling Material.*— The oxygen necessary for the proper work of an intermittent contact bed is abstracted with great energy from the atmospheric air, with which the pores become filled during periods of rest. Through diffusion, and through the vacuum created by the processes of absorption, further quantities of oxygen are taken from the atmospheric air, even under difficult conditions, and, as pointed out in the Manchester report for the year ending 27th March, 1901, "there is, therefore, little need to force air into a bed."

The oxygen taken up during aeration is not imparted to the sewage at the next filling and does not escape in the effluent.

The oxygen thus taken up is not imparted in gas form to the sewage during the next filling, and the effluents from intermittent contact beds are not saturated with oxygen. Dunbar states that the effluents of a satisfactorily worked bed frequently only contain one cubic centimetre of free oxygen per litre. Clowes reports a similar result in his third report on the London experiments.

The greatest quantity of oxygen is consumed during the oxidation of the products formed by micro-organisms.

There can be no doubt that by far the greatest quantity of oxygen is consumed during the process of oxidation of the products formed by micro-organisms from putrescible organic substances.

Consumption of oxygen and formation of carbonic acid not solely due to biological agencies.

(*f*) *Formation of Carbonic Acid.*—Dunbar has shown by his experiments that the consumption of oxygen and the formation of carbonic acid is not solely due to biological agencies, but is to some extent the result of physico-chemical processes.

More free carbonic acid contained in the effluent than in the raw sewage.

He further reports that in his experiments the effluents contained on an average 100 milligram per litre more free carbonic acid than the raw sewage, and that the quantity contained in the effluents represents only a small portion of the total amount of carbonic acid formed during the whole process. The by far greatest portion of carbonic acid escapes into the air. Concerning the air in the pores of the filling material during periods of aeration, Dunbar states that it contains sometimes not less than from 6 to 10 per cent carbonic acid.

By far the greatest portion of carbonic acid escapes into the air.

Nitrogen escapes in gas form into the air.

(*g*) *Nitrogen.*—It is quite clear from all experiments that a considerable amount of the total nitrogen contained in raw sewage is abstracted by the filling material of intermittent contact beds, and it is interesting to ascertain what becomes of it! Does it accumulate in the bed? In that case, one has a right to assume that the satisfactory work of the bed would gradually cease! As this is, however, not the case, and as, further, the sludge formed in the bed, whether it be fairly fresh or very stale, only contains a very small amount of total nitrogen, we must surmise that the nitrogen after its retention by the bed escapes in gas form—like the carbonic acid—into the atmosphere.

The presence of nitric acid is not an unfailing guide for determining the satisfactory character of the effluent.

(*h*) *The Formation of Nitric Acid.*—Concerning the presence of nitric acid in the effluents from intermittent contact beds, Dunbar is of opinion that it offers certain means for forming an opinion of the processes taking place in the same, but that it is only in a subordinate sense an indication of the degree of purification attained

and must not be taken as an unfailing guide for determining the satisfactory character of the effluent.

Nitrifying bacteria are always present in ordinary town's sewage, but it would appear that other micro-organisms besides Winogradsky's bacteria assist in the process of nitrification. Nitric acid is formed very rapidly, but only during periods of rest, and besides aeration other less powerful influences are at work.

Nitrifying bacteria always present in town's sewage.

Nitric acid is formed very rapidly, but only during periods of rest.

It is further interesting to note that, according to Dunbar, the greater portion of nitric acid which has been formed during periods of aeration becomes completely reduced in a very short time, when the bed is filled with an upward flow from the bottom, and that only a small portion remains in the form of nitrous acid.

Reduction of nitric acid when bed is filled from bottom with an upward flow.

3. Artificial Self-Purification of Sewage in Septic Tanks.

Although it has never been claimed, and is further not open to doubt, that a septic tank alone and unaided by subsequent treatment in intermittent or continuous contact beds does not sufficiently purify the sewage, in these remarks the work of the septic tank only will be considered, as the treatment in contact beds will be dealt with separately.

Septic tanks only used in combination with contact beds.

(*a*) *Name of Septic Tank.*—A good many names have been suggested by different observers—such as "anaerobic fermentation tank," "putrefying tank," "liquefying tank," "cess-pit," etc.—but there appears to be no reason why the name "septic tank" should not be adhered to, as it describes sufficiently correctly the work done by the tank, which is chiefly of a septic nature.

Septic tank a suitable name.

(*b*) *Covered or Open Septic Tank.*—Before dealing with the processes taking place in a septic tank, it will

not be out of place to consider here, shortly, whether a closed septic tank confers advantages over an open septic tank sufficiently great to justify the considerably greater expenditure necessitated by its construction.

It is well known, that at Exeter in the first experimental installation of this process, the septic tank was covered in byan arched roof; but subsequent experiments made elsewhere do not seem to support the theory then advanced, that such a tank should be a closed one. This is chiefly due to the thick skin which, after a few months' work, forms on the surface of closed or open tanks, and which according to locality and season may reach a thickness of from 1 to 2 feet; it is maintained then that this cheap natural cover does away with the expensive artificial cover.

In the report on the treatment of the Manchester sewage, by Messrs. Baldwin Latham, Percy F. Frankland and W. H. Perkin, it is stated on page 54, amongst the conclusions and recommendations, as follows:—"The anaerobic or septic process is found to take place as effectively in an open tank as in a closed one." This conclusion does not appear to have been modified by the experiments made subsequent to the issue of this report.

In the Leeds experiment a similar result was obtained.

Closed septic tanks possess generally speaking no advantages over open ones.

Whilst it would, therefore, appear to be correct to say, generally, that closed septic tanks afford no material advantages over open ones, so far as the purification of the sewage is concerned, they may become necessary in special cases, when the smells emanating from open ones might create nuisances in crowded neighbourhoods.

The following remarks refer, therefore, equally to open as well as to closed septic tanks, and no distinction will be made between them.

(*c*) *Explanation of Process.*—Although the processes taking place in septic tanks are at present but imperfectly understood, they may be said to be in the main due to anaerobic micro-organisms, i.e. due to such micro-organisms which carry on their life's work in the absence of oxygen. They split up or peptonise the organic compounds in the absence of air, and the group of changes brought about by them has been termed "anaerobic fermentation" or "putrefaction." During the same, it is claimed that a considerable amount of the sludge retained in the tank is liquefied or destroyed, and that the rest becomes so changed as to be denser than ordinary sludge, and to contain less moisture.

The work in the septic tank is chiefly done by obligatory anaerobes.

Concerning the amount and nature of the dissolved matters entering and leaving an open septic tank, the following is taken from the Manchester report for the year ending March 27, 1901 :—

Dissolved matters entering and leaving the septic tank.

"A series of determinations have been made of the amount of dissolved matter entering and leaving the tank, by evaporating known volumes of the sewage and effluent after filtration through paper and weighing the solid residue.

Manchester observations.

"An average of six determinations (confirmed by similar observations in connection with the closed septic tank) gave the following results :—

Raw Sewage. Dissolved matter, grains per gallon.			Open Septic Tank Effluent. Dissolved matter, grains per gallon.		
Mineral.	Organic and Volatile.	Total.	Mineral.	Organic and Volatile.	Total.
33·0	33·0	66·0	30·8	25·0	55·8
			Reduction, in per cent.		
			6·67	24·24	15·45

"A certain amount of loss of ammonia, as ammonium carbonate, will take place on evaporation in both cases, and this will probably be greater with septic tank effluent.

"An examination of the residue obtained by evaporating large quantities of open septic tank effluent (filtered through paper), shows that the mineral matters largely consist of iron oxide, from the decomposition of organic compounds of iron, and calcium sulphate. Among the volatile constituents have been detected ammonium carbonate, mercaptan-like compounds of very offensive smell, acetic and butyric acids. No evidence of the presence of amines could be found in the residue on evaporation, but by distilling large volumes of the liquid and carefully analysing the platinum salts obtained from the distillate, the presence of amines is indicated.

"Research in this direction is being continued; careful comparison especially will be made of the products obtained by evaporation and distillation of crude sewage and septic tank effluent respectively.

"The evidence, however, points to a breaking down of albuminoid and cellulose matter in the septic tank into simpler and to some extent volatile compounds. The reactions are probably hydrolytic in character, ammonia, amines, carbonic acid, water, and possibly alcohol, being produced.

"A further quantity of organic matter also disappears as methane, nitrogen and hydrogen."

Must aerobic fermentation in all cases be preceded by anaerobic fermentation?

It will be clear from the foregoing, that the changes going on in a septic tank are entirely different from those brought about in contact beds, and the question whether a septic tank is a necessity for the subsequent contact bed treatment, or whether it is a distinct disadvantage, can only be definitely settled when we know

whether aerobic fermentation, i.e. decomposition, must in all cases be preceded by anaerobic fermentation, i.e. putrefaction, and to what extent, or whether such a succession of changes is not necessary.

It is interesting to note in connection with this point, that during the Manchester experiments it was established that contact beds, which have become accustomed to septic tank effluent, will not at once purify comparatively fresh sewage.

At Manchester contact beds accustomed to septic tank effluent did not at once purify raw sewage.

(*d*) *Velocity of Flow through Tank.*—The velocity of flow through the septic tank is of great importance, as on it depends the size of the installation.

It seems to have become a habit to express this velocity by the length of the sojourn of the sewage in the septic tank—for instance, "the flow of sewage through the tank was such that it would fill it in twenty-four hours"; but as all tanks vary in size, and as in consequence the distance which has to be traversed by the sewage from the entrance to the exit in twenty-four hours is different in nearly every case, such a habit is, to say the very least, very misleading.

It will not be disputed that the deposition of the suspended solids in sewage is dependent on the rate of movement of the liquid, and that in a quickly moving liquid there will be less deposition than in a very slowly travelling liquid.

Bearing this in mind it will not be without interest to examine the velocities employed during the Manchester

Town.	Length.	Width.	Depth.	Contents.
	feet.	feet.	ft. in.	gallons.
Manchester tanks . .	300	100	6 0	1,125,000
Leeds " . .	100	60	7 7	250,000

and Leeds experiments. The tanks employed in these have the dimensions given in the table on the preceding page.

Now assuming that each tank is to be filled once in twenty-four hours we obtain the following velocities :

$$\text{Manchester} \quad \frac{300' \, 0'' \times 12''}{1440} = 2'' \cdot 5 \text{ per minute.}$$

$$\text{Leeds} \quad \frac{100' \, 0'' \times 12''}{1440} = 0'' \cdot 84 \text{ per minute.}$$

Which means that in the Manchester experiments the velocity would have been three times as large as in Leeds ; and it is clear that if the sewage of both towns was identical the results, so far as the retention of the suspended matters in the tanks are concerned, could not have been identical. As a matter of fact, considerably greater velocities have been used in the Manchester experiments, as will be shown later on.

Rate of flow through septic tanks should not be expressed by the length of sojourn in tank but by some linear measurement in a stated time.

It will be clear from this, that it is most misleading and erroneous to express the rate of flow by the length of the sojourn of the sewage in the tank, and that the velocity should in each case be expressed by some linear measurement in a stated time—probably inches per minute.

The next point to consider is the velocity to be employed in septic tanks ; and here it is not without interest to refer to the various experiments enumerated with their results in the next table.

The difference in the results obtained, so far as the suspended matters are concerned, is probably due to the different character of the various sewages experimented with ; but so low a velocity as 0·52 inch, as used in the Exeter experiments, does not appear to be necessary.

In the Leeds experiments, it was found that the filling of the tank once in twenty-four hours gave the best results ; and as the velocity then was 0·84 inch per

SEPTIC TANK EXPERIMENTS.

Rate of Flow and Deposition of Suspended Matters.

No.	Name of Town.	Rate of Flow.		Suspended Matters in Sewage.			
		Length of Sojourn of Sewage in Tank.	Velocity of Flow per minute.	Remaining in Tank.	Destroyed and Liquefied in Tank.	Leaving Tank in Effluents.	Total.
		days.	inches.	per cent.	per cent.	per cent.	
1	Exeter	1·0	0·52	17	39	44	100
2	Manchester	0·44	5·58	41	22	37	100
3	,,	0·56	4·44	23	33	44	100
4	Leeds	0·5	1·68	..	..	..	..
5	,,	1·0	0·84	average say	28	..	..
6	,,	2·0	0·42	..	..	..	..

second it will be somewhat near the mark to recommend generally a velocity of 1 inch per minute. On the assumption that the sewage shall remain twenty-four hours in the tank, this gives a length of tank of 120 feet, which is a very suitable one.

Septic tanks reduce the sludge difficulty to some extent, but do not altogether remove it.

(*e*) *Destruction and Liquefaction of Sludge in Septic Tanks.*—It was formerly maintained that the employment of a septic tank did away with all sludge difficulties, and one sees even now advertisements to that effect, that there is "no sludge" with a septic tank; but experience everywhere does not bear out this contention. On the contrary, there must be sludge with a septic tank, and the only question one has to consider is, to what extent does a septic tank reduce the quantity of sludge?

The table above contains the results obtained in the various experiments, and from these it would appear as if on an average, with a velocity of 1 inch per minute, 25 per cent. of the total sludge would be destroyed or

liquefied in a septic tank. Generally speaking, therefore, the following figures will be somewhat near the mark, where the plant is worked systematically and carefully supervised.

	Per cent.
Suspended matters remaining in tank	35
,, ,, destroyed or liquefied in tank	25
,, ,, escaping in effluent	40
Total	100

These figures mean that 35 per cent. of the total suspended matters will have to be dealt with as sludge, 25 per cent. will be destroyed or liquefied in the septic tank, and the remaining 40 per cent. will be deposited on and in the contact beds.

It has already been pointed out that it is claimed that the septic tank sludge is denser and contains less moisture than ordinary sludge, and that about half of it is mineral matter.

As previously stated, at Manchester a reduction of about 16 per cent. in the dissolved matter has been observed in the open septic tank.

(*f*) *Formation of Gas in Septic Tank.*—It was at one time suggested that the gases formed in septic tanks during anaerobic fermentation might be utilised for lighting or heating purposes, but anyone well acquainted with the subject will admit that such a use is outside the range of practical possibilities.

At Manchester, 100 gallons of sewage evolved in twenty-four hours about a cubic foot of gas, which on an average contained :

	Per cent.
Marsh gas, CH_4	73
Carbon dioxide, CO_2	6
Hydrogen, H	5
Nitrogen, N (by difference)	16
Total	100

At this rate 1 million gallons of sewage will evolve 10,000 cubic feet of gas, or 0·2 tons of gas, in twenty-four hours.

(*g*) *Mixing Action of Septic Tank.*—There is one advantage possessed by a septic tank which cannot be disputed, and that is the mixing action going on within it. The fresh sewage on its arrival becomes mixed with stale sewage, and, owing to the rising of lumps of sludge from the bottom, and other causes, the contents of the tank become of a more uniform composition, which must entail a corresponding advantage for the subsequent contact bed treatment.

Septic tank effluent more suitable for nitrification.

(*h*) *Micro-organisms in Effluent from Septic Tank.*—Although the available number of experiments on the micro-organisms contained in the effluent from a septic tank is not large, yet they support the conclusion which one would form by analogous reasoning, that so far as the bacterial flora is concerned the effluent is practically raw sewage.

The septic tank effluent is so far as bacterial purity is concerned practically raw sewage.

4. Continuous Contact Beds.

It is necessary to make at this point a few short observations on the artificial self-purification in continuous contact beds.

Continuous contact beds still in an experimental stage.

This method of artificial purification has frequently been called "continuous filtration," but it will be much better to reserve the term "filtration" for the percolation of water through fine material, such as sand, and to call the continuous flow of sewage through coarser material continuous contact bed treatment, as the processes going on during the same are more analogous to those going on in an intermittent contact bed than to those taking place in a waterworks filter.

Formerly it was attempted to use the same kind of contact bed for continuous treatment as is used for intermittent treatment, but, as was to be expected, the results obtained were so unsatisfactory that the experiments had to be discontinued. Now somewhat different forms are utilised, which are mostly protected by patent rights, and the mode of distribution has also been altered by the introduction of patent distributors or sprinklers, which cause the sewage to fall in very thin streams upon the filling material.

In the Manchester experiments, the proprietary continuous contact bed does not appear to have given satisfactory results. Better effluents were obtained at Leeds, and at York the results obtained are said to have been very good.

On the whole, however, it is but right to say that the experience gained so far is not sufficient to entitle us to form definite opinions, and for this reason it will be better to await further results.

VI. MANAGEMENT OF PLANTS FOR THE ARTIFICIAL SELF-PURIFICATION OF SEWAGE.

Plants for the artificial self-purification of sewage require very careful handling.

It was formerly frequently concluded that neither septic tank nor contact beds required careful superintendence, but that they could be worked by automatic machinery and left to themselves. It was therefore maintained that the working expenses of plants of this nature would be next to nil. This was, however, not Mr. Dibdin's view, who, after years of careful study, came to the conclusion that they were delicate pieces of mechanism which required careful watching.

Since, Mr. Dibdin's conclusions have been amply confirmed by all careful experimenters.

For instance, Mr. Fowler, the chemist in charge of the Manchester experiments, observed before the Royal Commission on Sewage Disposal as follows: "It is a delicate operation (the management of septic tank and contact beds), which requires careful watching! There is no doubt whatever about that!" (Question 5651.)

Again, the conditions of successful working of contact beds, laid down by the same gentleman on page 64 of the Manchester report for the year ending March 27, 1901, are ample proof of this, and they show very clearly how extremely careful the supervision of such a plant ought to be, and that in the hands of inexperienced men it will soon come to grief.

Professor Percy Frankland stated in his evidence before the Royal Commission, that in his opinion land required less skilled supervision than contact beds. (See Questions 9937, 10071–74.)

A similar view was expressed by Mr. H. M. Wilson, the chief inspector of the West Riding of Yorkshire Rivers Board. (Question 6380.)

VII. SOME OBSERVATIONS ON THE DEPOSITION OF SUSPENDED MATTERS IN TANKS.

Definition of the term "deposition."

The term "deposition" shall here be held to mean the precipitation of the suspended matters without chemicals or other artificial means, i.e. the unaided subsidence of these matters at such a rate of flow that septic action is not set up within the tanks.

The question that is of interest here, is: Which is the most favourable rate of flow of the sewage through

the tank, so far as the deposition of the suspended matters is concerned? To some extent the answer to this question will depend on the special characteristics of the particular sewage under consideration, but for general purposes the following observations will not be without interest.

Although of very great importance, this question does not appear to have received very general consideration, as the available number of careful experiments is but small.

Tank velocity at Barking. It appears that the calculated velocity in the channels of the precipitation tanks at Barking is about 4 feet per minute, and that with this velocity about 77 per cent. of the suspended matters were deposited in the year 1894.

Tank velocity at Manchester. At the Manchester tanks it is stated that a velocity of 3 feet 4 inches per minute is employed.

Velocity frequently adopted. A rate of velocity now frequently adopted in this country for new works is 6 inches per minute.

Frankfort experiments. In the settling tanks at Frankfort on the Main there are deposited about 84 per cent. of the suspended matters, with velocities ranging from 9½ inches to 16½ inches per minute.

Cassel experiments. With a velocity of 7 inches per minute, it is stated that at the Cassel sewage works 97 per cent. of the suspended matters are retained in the tanks.

Hanover experiments. At Hanover a set of interesting observations has lately been made, on tanks 246 feet long, with a view to ascertaining the most advantageous rate of flow.

With a velocity of 9·44 inches per minute, 62·7 per cent. of the suspended organic matters were precipitated, with a velocity of 14·17 inches per minute 61·7 per cent. were deposited, and with a velocity of 35·43 inches per minute 57·3 per cent.; from which figures it will be clear that there is not much difference in the result on the suspended matters between these velocities.

Against these results must be placed the results obtained with septic tanks, where, as has frequently been stated, a velocity of 1 inch per minute and a sojourn of twenty-four hours in the tank may be expected to lead to a deposition of about 60 per cent. of the suspended matters.

Reduction of cost.

Where, therefore, a previous septic treatment of the sewage by anaerobes is not necessary, it is clear that the substitution of ordinary settling tanks for septic tanks will be accompanied by a very considerable reduction of cost.

VIII. CONCLUDING REMARKS.

Since the foregoing observations were penned, the Chairman of the Royal Commission on Sewage Disposal has delivered a very interesting inaugural address, in August last, at the Congress in Exeter of the Institute of Public Health, to which attention ought to be drawn at this point.

According to *The Times* he is reported to have stated as follows : " He regretted that he could not give some idea of the probable date at which the Commission would issue its final report and recommendations. They would soon, he hoped, be able to publish the results of a prolonged investigation into the treatment of sewage on land ; and their experts were now making elaborate parallel examinations of some of the processes of filtration by artificial means. But he feared that they would ultimately be obliged to bring their proceedings to an arbitrary close ; for, however much they could learn, he was quite certain they could never come to a point at which they could say there was nothing more to be learned. The subject was inexhaustible."

These very guarded observations are almost in direct contrast with the very positive assurance of some enthusiastic supporters of artificial treatments, who a year or two ago did not hesitate in proclaiming throughout this country that the panacea for all sewage difficulties had been discovered, and that the investigations of the Royal Commission were a mere matter of form and a foregone conclusion.

To all those who did not share these very sanguine expressions of faith, and who were painfully aware of the great gaps in our knowledge of the processes taking place in sewage purification, these words of Lord Iddesleigh will prove an assurance that the commissioners are not swayed by popular likes and dislikes, however fascinating they may be, but that they are earnestly endeavouring, in an impartial manner, to throw such light upon this abstruse question as will enable them to arrive at correct conclusions.

For a like purpose the foregoing remarks have been written ; and if the facts recorded in the previous pages, and the opinions expressed therein, should prove of assistance to anyone in forming correct views, the labour spent on them will be amply repaid.

POSTSCRIPT.

SINCE the foregoing remarks were written, I have been somewhat struck with the views expressed at one or two meetings by some of those who ought to have the full facts of the case at their fingers' ends. There seems to be a considerable vagueness as to the sanitary results to be obtained by either the natural or one of the artificial methods of sewage treatment, and with a view to making this point quite clear I have prepared the following comparative statement (see next page), which, I trust, will show at a glance what one may expect from either system.

This statement has not been prepared from experimental installations, where, as a rule, better results are obtained than in actual every-day work ; but it refers to fairly large works dealing from day to day with the whole town's sewage. It has further been assumed, that the plant both for the natural as well as for the artificial treatment is suitable, and managed carefully and on intelligent lines.

As in all sewage treatments the sanitary results have first to be considered, I have only dealt with them in the statement, but even if I had extended it to economic considerations the result would have been practically the same.

From a careful examination of the facts recorded in the statement it follows that with natural treatment we get five distinct advantageous results, against which we have to place only two on the side of the artificial treatments ; but this means, that if we wish to bring up the results of these treatments to those obtained by the natural treatment, we have to supplement them by three

further treatments for the extraction of pathogenic germs, and of the manurial elements, and for the reduction of the liquid.

It is these facts which ought to be carefully considered by all those who wish to study the comparative advantages of these two systems, or who have to decide on a definite method to be employed in a particular case, and no step ought to be taken before every one of these five points has been very carefully weighed. Generally speaking, that system will be preferred which confers the greatest number of advantages.

Statement.

Results to be obtained from

(A) *Natural Treatment.*	(B) *Artificial Treatment.*
1. Removal of suspended matters.	1. Removal of suspended matters.
2. Removal of from 75 to 95 per cent. of the dissolved organic matters.	2. Removal of from 50 to 75 per cent. of the dissolved organic matters.
3. Removal of pathogenic germs.	3. Nil. Effluent bacterially practically raw sewage.
4. Utilisation of large portion of manurial elements.	4. Nil. All manurial elements escape into the rivers.
5. Great reduction of quantity of liquid.	5. No appreciable reduction of quantity of liquid.

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